SEWAGE WORKS JOURNAL

Vol. VIII JULY, 1936 No. 4

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Chemical Coagulation—Rudolfs

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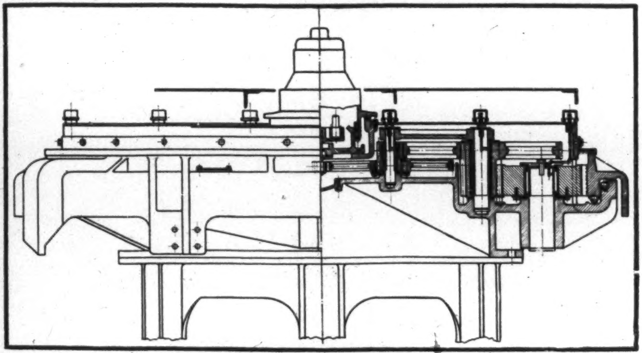

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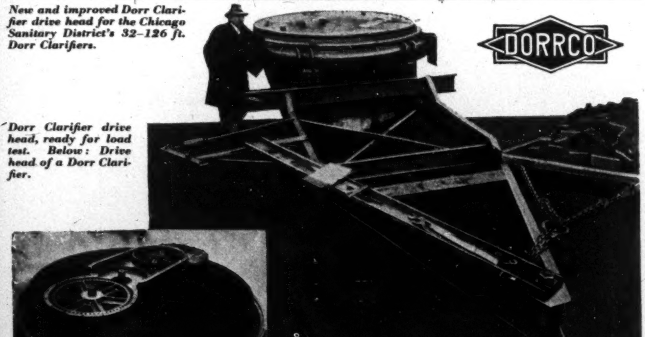

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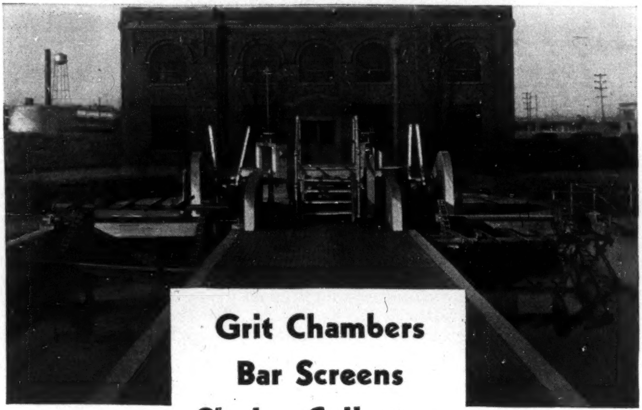

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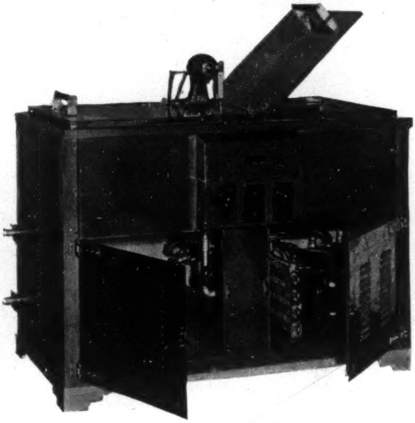

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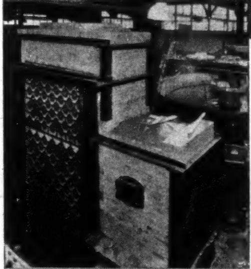

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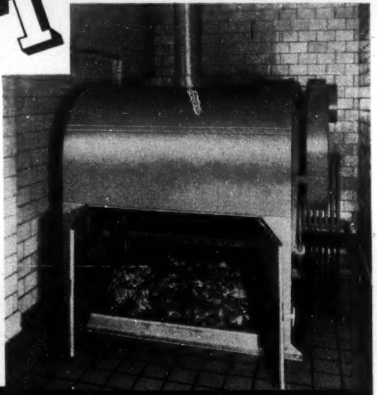

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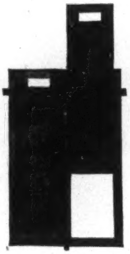

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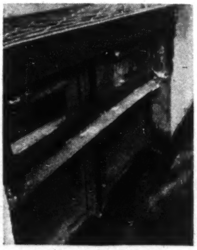

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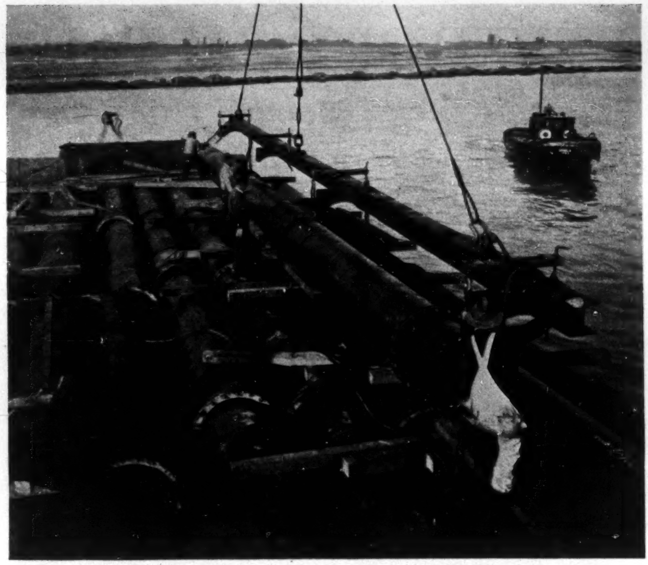

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Sewage Research

CHEMICAL COAGULATION OF SEWAGE*

IV. B.O.D. OF SOLUBLE AND DISPERSED MATERIALS

By Willem Rudolfs and H. W. Gehm

Chief and Assistant, Div. of Water and Sewage Research, New Brunswick, N. J.

Modern methods of chemical coagulation of sewage produce effluents with relatively high biochemical oxygen demand, when compared to the most effective biological methods. It is usually assumed that the soluble oxidizable substances present in the sewage, which are not coagulated or removed by the chemicals used, are responsible for these relatively high B.O.D. values. In order to obtain comparable information dealing with the reasons for the B.O.D. remaining in the effluents, laboratory experiments were performed to determine: (1) whether part of the soluble substances were removed by the coagulant, (2) whether more or different soluble substances were formed in treatment with different chemicals, (3) the nature of the soluble substances responsible for the B.O.D., (4) the effect of coagulants on the oxidation of the different fractions of sewage constituents. The results described in this paper deal more specifically with the removal or formation of soluble substances and the influence of iron salts on the rate of oxidation of the soluble fraction of the sewage. It is conceivable that the substances remaining in the effluent after chemical treatment consume oxygen at a more rapid rate than the dispersed materials. If, for instance, the oxygen consumption of the remaining materials, when diluted, is very rapid, it would be possible that the conditions in the stream immediately below the outfall or a short distance down stream would be no better or only slightly better than if plain settling were practiced. On the other hand, if the iron salt combined with the organic matter should cause a retardation of the oxidation for several days, chemical coagulation should receive more credit for alleviating pollutional conditions in the stream below the outfall than can be accorded by the 5-day B.O.D. determinations. It is also possible that the fixation of organic substances is sufficient to retard biological activities, thereby only postponing difficulties at downstream points in the stream.

The coagulant requirements of sewage in relation to the oxidizable substances present, together with additional information on the B.O.D. of effluents produced by different types of coagulants and B.O.D. values obtained over longer incubation periods, will be presented in another paper of this series.

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* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research. Presented before the 91st Meeting of the Am. Chem. Soc., Kansas City, Mo., Apr. 15, 1936.

PROCEDURE

The general procedure used in chemical treatment was as follows: Coagulant solution was allowed to drip into sewage samples accompanied by violent mixing. Samples of 1.5 liters were used, and a flocculation speed of 16 r.p.m. for a twenty-minute period was employed. Where settling was required one hour was allowed. Dilution water, seeded with 50 ml. of cotton-filtered sewage in 20 liters, was used for all B.O.D. determinations to eliminate any irregularities which might occur due to germicidal action of the $FeCl_3$ or removal of bacteria by filtration. Iron remaining in all effluents was determined and in none was the concentration, on dilution for B.O.D. determination, high enough to exert any influence on microbial activity. Samples having low and high pH values were adjusted to 7.0 before dilutions were made.

The sewage samples employed were of domestic origin and obtained from three communities. Two other sewages containing various industrial wastes were used and indicated as such in the test.

RESULTS

Since it is impossible to present all results obtained, only typical examples are given, and in a future paper more detailed and supporting data will be presented.

B.O.D. of Soluble Fraction After Complete Treatment. Fresh and stale sewages of varied strengths were treated with chemicals in three different ways, obtaining clear effluents in all cases. The pH values chosen for presentation were those producing maximum removal of suspended solids with small quantities of coagulant, namely: (1) with ferric chloride alone, (2) pH control with lime to 9.5 and 10 p.p.m. Fe as $FeCl_3$, (3) pH control with H_2SO_4 to 3.5 and 10 p.p.m. Fe as $FeCl_3$. After proper mixing, coagulation and one hour settling, the effluents, including a control to which no chemical had been added, were passed through a Seitz filter to remove the remaining finely divided and colloidal material. The 5-day B.O.D. was determined on the clear filtrates. Sewages of low and high iron requirements were also compared without pH adjustment and $FeCl_3$ alone used as coagulant.

TABLE I.—*Five-Day B.O.D. of Seitz Filtrates of Effluents (Expressed in p.p.m.)*

	Fresh Sewage			Stale Sewage		
	Min.	Max.	Ave.	Min.	Max.	Ave.
Untreated	90	132	113	103	150	120
15–20 p.p.m. Fe	87	134	114	109	128	118
10 p.p.m. Fe, pH 9.5 (lime)	93	157	116	97	152	121
10 p.p.m. Fe, pH 3.5 (H_2SO_4)	82	132	101	40	122	84

The minimum, maximum and average results of 5-day B.O.D. results of Seitz filtrates of effluents are shown in Table I. When comparatively small doses of $FeCl_3$ were required, little difference was found between the B.O.D. of the soluble fractions of the untreated and treated sewages. There was somewhat more variation with the stale sewages than with the effluents of the fresh sewages. With lime and iron salt treatment no appreciable difference occurred as compared with the untreated material. The differences between fresh and stale sewages were very small, if any.

Treatment of fresh sewages with sulphuric acid and $FeCl_3$ produced B.O.D. values of about 10 per cent lower than were found for the soluble fraction of the controls. This difference was materially amplified with stale sewages, where an average decrease of 30 per cent was noticed.

Sewage requiring large doses of coagulant without pH adjustment (40 to 60 p.p.m. Fe as $FeCl_3$) showed considerable reduction in the B.O.D. of the soluble fraction. Five examples of untreated and treated fresh and stale sewages showed the following 5-day B.O.D. results in p.p.m.:

						Ave.
Untreated	106	142	128	102	92	114
40 to 60 p.p.m. Fe	75	75	98	80	52	74

The apparent reduction in B.O.D. was material and averaged for these samples about 30 per cent.

B.O.D. of Fractions.—Further tests were made (1) to determine which fraction of the sewage has the greatest oxygen demand and the greatest rate of oxygen consumption; (2) to find the relationship between the volatile matter content of each fraction of the sewage constituents and 5-day B.O.D.; and (3) to compare the effect of coagulants on the different fractions from the standpoint of oxygen demand. The sewage samples were divided into three fractions, namely, screened, cotton-filtered and Seitz-filtered liquors. The B.O.D. rates were determined for each fraction, together with the total solids and volatile matter content. The average B.O.D. of the different fractions for three samples are shown in Table II.

TABLE II.—*B.O.D. of Sewage Solids*

	Coarse	Finely Divided	Soluble
5-day B.O.D., p.p.m.	89	76	75
Vol. Matter, p.p.m.	128	20	197
Mgr. O_2 Consumed per Mgr. Vol. Matter	0.70	3.80	0.38

The oxygen required in five days by the volatile matter in the different fractions was fairly equal, but on the basis of equal weights of volatile matter the soluble fraction had the lowest demand. The coarse material exerted about twice, and the finely divided as much as ten times the demand of the soluble volatile matter. Expressing it differently, the B.O.D. of the volatile matter of the settlable solids is relatively unimportant as compared with the material passing out a settling tank, so that 10 p.p.m. of finely divided volatile material in the effluent is equal to 50 p.p.m. volatile settled solids. Although attention has been called repeatedly to the fact that in chemical coagulation we are especially interested in the finely divided material these figures emphasize the statements.

Due to the relative simplicity and the nature of the soluble substances it would be expected that smaller amounts of oxygen are necessary than for the more complex substances in the finely divided and coarse materials. The coarse materials, being less available from both a mechanical and chemical standpoint for biological action, are not oxidized in 5 days to the same extent as the finely divided or soluble substances. The finely divided and colloidal fraction contains material easily available to bacteria, in spite of the fact that the organic matter is highly complex in nature, with the result that these materials are practically completely oxidized in the 5-day incubation period. During the first three days of incubation the rates of oxidation are practically identical, but begin to diverge thereafter. This is illustrated in Fig. 1, where the B.O.D. rates of the different fractions are shown for a period of 5 days. If the B.O.D. rates for the different fractions are compared on an equal volatile matter basis the oxygen requirements of the coarse material eventually approaches that of the finely divided and colloidal substances.

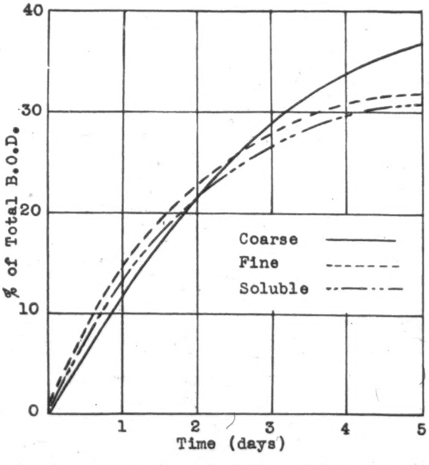

FIG. 1.—Rates of oxidation of coarse, fine and soluble materials, expressed as percentages of total B.O.D.

B.O.D. of Soluble and Colloidal Material of Different Sewages.—Since it has been shown above that feasible dosages of $FeCl_3$ or $FeCl_3$ and lime have no great effect on the soluble B.O.D., and that the rate

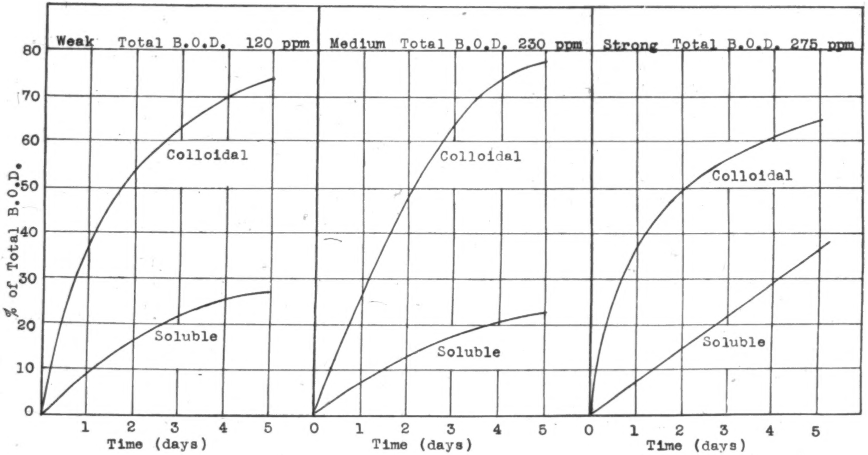

FIG. 2.—B.O.D. rates of colloidal and soluble substances in normal sewages of varied strength.

of oxygen consumption for the soluble and finely divided materials was nearly the same for sewages of similar characteristics, experiments were performed to determine the oxidation of varied types of sewages. Cotton and Seitz filtrates were used of domestic sewages of varying strength and of sewage containing industrial wastes.

The B.O.D. rates of colloidal and soluble materials for a period of five days, using weak, medium and strong domestic sewage, are graphically shown in Fig. 2. It is of interest to note that the rates of oxygen demand of the finely divided materials are not appreciably different for the sewages of various strengths, but the more important fact is that the soluble material does not exert a great immediate demand. As a matter of fact the rate of oxidation of the soluble material is even slower than that of the colloidal material. It is conceivable, however, that when the soluble material is increased by the addition of trade wastes capable of biological oxidation, the rates of oxidation may materially change. Two examples of sewages containing trade wastes, one having equal soluble and colloidal 5-day B.O.D. and the other higher soluble than colloidal (Fig. 3), illustrate, however, that the rate curves are not far different from the soluble and colloidal substances present in normal sewage.

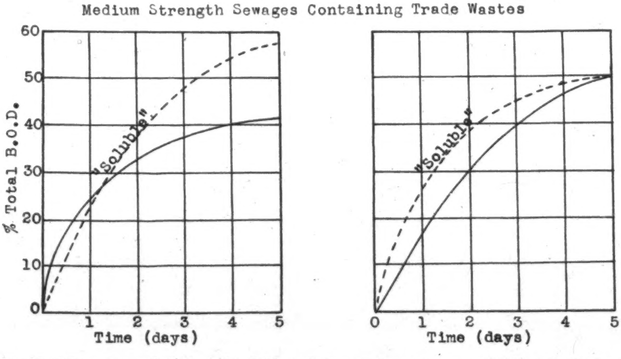

FIG. 3.—B.O.D. rates colloidal and soluble substances in sewages containing trade wastes.

These results mean that a well clarified effluent produced by smaller quantities of iron salt, or by iron coagulant and lime, would not have a greater immediate oxygen demand than settled sewage clarified to the same degree. In practice this would mean that the clearer effluent from chemical coagulation exerts relatively less immediate effect upon the stream. This holds also for sewage effluents containing industrial wastes. At the same time, the greater the fraction of soluble substances capable of oxidation, the greater the effect on the stream, because these soluble substances are not removed by small quantities of iron salt alone or iron salt and lime treatment. For a reduction of the

B.O.D. of the soluble fraction, acid pH adjustment is valuable. Similarly, with large quantities of ferric chloride, the B.O.D. of the volatile matter in the soluble fractions decreases.

EFFECT OF $FeCl_3$ ON THE RATE OF B.O.D. REDUCTION

When the sewage requires large quantities of $FeCl_3$ for coagulation a decided reduction in the 5-day B.O.D. of the soluble fraction takes place. To determine the magnitude of the effect in relation to the amounts of $FeCl_3$ added and the effect on the rate of oxidation for both the finely divided and soluble substances, cotton filtered sewage was treated with from 0 to 50 p.p.m. Fe as $FeCl_3$. After flocculation each sample was shaken to suspend the floc through the liquid, and the B.O.D. rates were determined on the mass. A series of results are shown in Fig. 4.

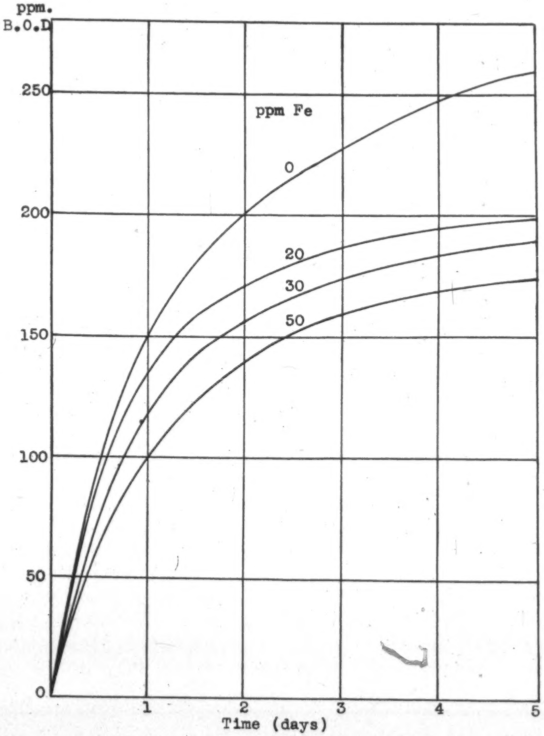

FIG. 4.—Effect of amount of ferric chloride on B.O.D. rates of cotton-filtered sewage.

The curves show a gradual B.O.D. reduction with the increase in iron salt dosage. The shape of the curves does not exhibit the characteristics of rate curves obtained when toxic substances are present. The reduction with increasing amounts of iron indicate a removal or fixation of the organic material. The question of formation of an organic iron complex resistant to biological activities will be discussed at greater length in another paper when results on other iron salts will also be published; suffice it to say that this material is not decomposed after a ten-day incubation period.

The depressive effect of $FeCl_3$ treatment on the oxidation of finely divided and soluble sewage substances can also be demonstrated by the change in rate and amount of carbon oxidized. Aerating samples of treated and untreated cotton-filtered sewage and measuring the carbon-dioxide evolved over a period of days (Fig. 5) resulted in a decidedly lesser amount of carbon oxidation with the treated sewage. The example given in Fig. 5 is the average of two cotton-filtered sewages treated with 30 p.p.m. Fe as $FeCl_3$. Before aeration the treated sample was seeded to offset the possible germicidal effect of the added iron salt. With this particular dosage of coagulant the amount of carbon oxidized in 5 days was about 23 per cent less than of the untreated sample.

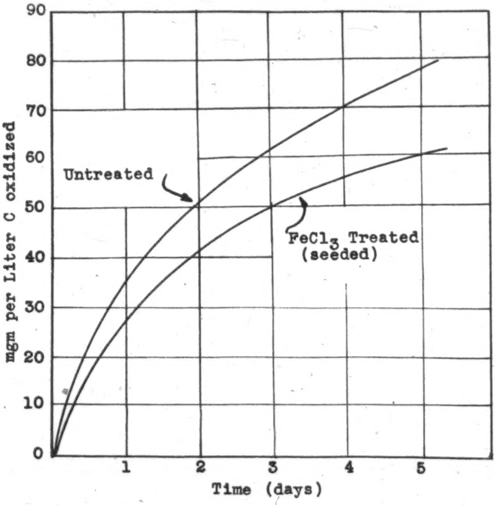

FIG. 5.—Effect of ferric chloride on carbon oxidation.

Discussion

In our discussion of the results it has been assumed that the Seitz filtrate consisted of "soluble" material. It is probable, however, that the oxidizable material passing through this type of filter is not truly soluble, but consists, in part, of material of an extremely finely divided colloidal nature. The Seitz filtrate, designated for convenience by us as soluble, was crystal clear, exhibiting no Tyndall effect. While the oxidizable portion was not necessarily molecularly dispersed or in absolute solution, it comprised that portion not removed from the solution by ordinary chemical coagulation. For this reason it has been considered for practical purposes as liquid containing "soluble" oxidizable material, incapable of settling, which is discharged into the stream after chemical coagulation. In this respect it is also of interest to note, that in the studies on colloids conducted at the University of London for the Water Pollution Research Board (1) considerable organic nitrogen and organic carbon was found in ultra-filtrates of sewage. A portion of these ultra-filtrates could be coagulated by gas bubbles, which might indicate the presumed extremely fine colloidal material.

The fractions designated as "colloidal" consist of colloidal, pseudocolloidal and finely suspended materials which will not settle under quiescent conditions in several hours, so that this fraction ordinarily passes through a settling tank. Although the designation of "colloidal" is obviously incorrect, the common usage in sewage treatment was followed, both for "colloidal" and "soluble" material.

It is conceivable that the use of an ultra-filter would have allowed a somewhat more accurate use of the two terms, but similar objections could have been raised. An ultra-filter is extremely slow and the quantity of liquid required is comparatively large for the type of experimentation conducted. With a Seitz filter larger quantities of material can be obtained within a reasonable time, and the practical reason had considerable weight in adapting the method, which is admirably suited for this work.

For practical purposes, the question of most interest is whether part of the "soluble" substances are removed either by coagulation or oxidized by an iron salt in operation of a sewage plant. The evidence presented indicates that neither coagulation nor oxidation takes place, but that there is, under certain conditions, a definite delay of biological oxidation. When acids are used for reaction control it appears that a part of the soluble material is either hydrolyzed or changed in such a way, that the materials, in part, are not oxidized biologically for a number of days, when comparatively large quantities of ferric chloride are used as a coagulant.

Summary

Laboratory experiments on chemical coagulation of different types of sewages show that small doses of ferric chloride neither render soluble nor oxidize nor inhibit oxidation of the soluble sewage substances.

High lime dosages in conjunction with iron coagulant also fail to act in either of these capacities. Reaction control with sulphuric acid, followed by $FeCl_3$ and large quantities of iron coagulant, tends to change some of the oxidizable substances of the soluble fraction in such a manner that they are not oxidized by the microorganisms for a period of 10 days.

The amount of oxygen required by the coarse, finely divided and soluble fractions for equal quantities of volatile matter was lowest for the soluble and highest for the colloidal fraction, the latter being ten times as much as the soluble.

The rate of oxidation of the colloidal and soluble organic substances is similar, although the ratio of oxidation of the soluble is somewhat slower than that of the colloidal material. After 5 days incubation the soluble and colloidal material is nearly completely oxidized, whereas the coarse substances continue to undergo oxidation.

Increasing quantities of $FeCl_3$ produced an increasing B.O.D. reduction of soluble and colloidal substances. The decrease was not due to toxicity of the coagulant, but indicated a removal or fixation of the organic materials.

REFERENCE

1. Rept. British Water Poll. Res. Bd., 1934, 32–36.

CHEMICAL COAGULATION OF SEWAGE.*

V. MIXING OF CHEMICALS AND FLOCCULATION

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The value of proper mixing and conditioning to obtain good clarification with a minimum amount of chemicals is well known in water works practice. To obtain maximum efficiency from any coagulant in sewage coagulation, the chemical must be properly mixed with the sewage and time allowed for coagulation to form a rather dense, rapidly settling floc. For water treatment Hyde[4] states, in his discussion on the practical aspects of water coagulation, that the coagulant should be rapidly and completely mixed with the water for uniform distribution. To obtain maximum efficiency in water from any coagulant it must be properly coagulated and "the largest possible mass of floc formed in the mixing chamber." Turbulent, preferably rotary motion is necessary. The period for floc formation varies according to Willcomb[9] and Hyde[4] from 20 to 30 minutes after mixing. Hoover[3] indicates from 30 to 60 minutes, while Eldridge, Mallmann and Theroux[1] recommended stirring sewage for at least 30 minutes. For proper floc formation, Luther[5] recommends 15 minutes for the sewage at Freeport, L. I. The performance of the Guggenheim apparatus in its first stage of chemical coagulation of sewage at the North Side Works of the Sanitary District of Chicago clearly demonstrated the value of thorough mixing.[6] To preclude reduction of iron in ferric salts and avoid indifferent coagulation, Enslow[2] states that air blowing or prechlorination to oxidize reducing compounds in sewage is essential.

Although some general rules are known to apply in regard to the requirements for mixing and flocculation in sewage coagulation, considerable uncertainty exists and knowledge of the optimum conditions is lacking. An attempt is made in this paper to evaluate (*a*) some types of mixing and flocculating methods, (*b*) to determine the effect of speed of mixing on coagulation and agitation during flocculation on floc formation and clarification, and (*c*) to indicate the possible effect of settlable solids concentration on the time and speed of flocculation.

Mixing Chemicals with Sewage

In an effort to determine the effect of speed of mixing on coagulation and subsequent floc formation, as well as on the removal of suspended solids after a given time of quiescent settling, it is necessary for our purpose to distinguish between the conditions during the actual mixing of the chemicals with the sewage and the conditions of agitation during flocculation. Theoretically it is rather difficult to demonstrate where coagulation stops and flocculation begins, but for practical purposes, with comparatively small quantities of chemicals, coagulation is considered to be accomplished when the chemical has been thoroughly mixed and before visible floc is formed.

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* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

Procedure.—To simulate possible plant conditions, four methods of distribution of chemical were chosen for experimental purposes. (1) Violent mixing, accomplished by rapidly raising and lowering a propeller paddle in a round battery jar containing sewage, while the chemical was fed drop by drop from a pipette. (2) Rapid mixing, by stirring the sewage in a horizontal rotary motion with a paddle speed of 100 to 120 r.p.m. and adding the chemical dropwise to the sewage. (3) Slow mixing of the chemical with the sewage, with a paddle speed of 15 to 22 r.p.m., which was approximately the speed employed for subsequent flocculation. (4) The addition of the chemicals below the surface of quiescent sewage and allowing two-minute intervals before flocculation. The total mixing time with the other methods was kept constant and lasted for one minute.

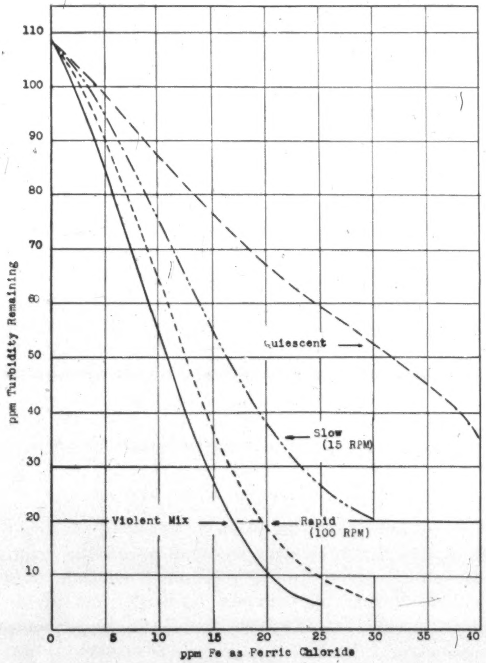

FIG. 1.—Effect of rate of mixing of chemical upon clarification.

For the experiments presented, ferric chloride and chlorinated copperas were used; as coagulants calcium hydroxide and sulphuric acid, were regarded as chemicals suitable for pH control. Turbidity measurements were used as indices of clarification, and the final pH values as indices of adjusting chemical efficiency.

Results.—A comparison of four different ways of mixing, using increasing quantities of ferric chloride is graphically shown in Fig. 1. It is apparent that best results were obtained with mixing of the most rapid type. The difference between violent and rapid mixing was comparatively small, but results with violent mixing allowed a slight reduction of chemical dosage. Mixing at slow speed and addition of chemical to quiescent sewage produced increasingly poorer results with the same quantity of coagulant. At slow speed it was necessary nearly to double the quantity of coagulant to obtain the same turbidity removal as with violent mixing. With quiescent addition, good results could be obtained only with large quantities of coagulants.

Chlorinated copperas behaved in a manner similar to ferric chloride. This is illustrated in Fig. 2, where the two chemicals are compared at the same speeds of mixing. The results given are typical, using as a basis the quantities of coagulant needed to produce optimum coagulation at violent mixing speeds.

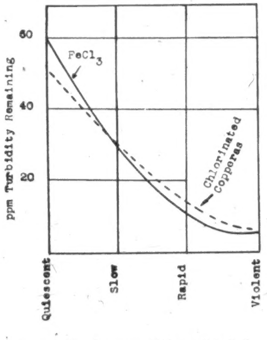

FIG. 2.—Comparison of iron salts in quantities added for optimum coagulation with violent mixing.

With the addition of chemicals for pH adjustment the same procedures were used for mixing. Lime or sulphuric acid was added in pre-determined quantities and the iron coagulants added drop by drop during mixing. Two series of results are presented in Fig. 3 with the addition of 2.5 and 5 p.p.m. Fe as $FeCl_3$. The importance of rapid mixing, when a ferric coagulant is used after lime treatment, is clearly indicated. The smaller the amount of coagulant the greater the effect of thorough and rapid distribution of the chemical. Again, similar results were obtained when chlorinated copperas was used as coagulant.

In respect to the effect of the speed of mixing upon the subsequent clarification of the sewage, the question of sequence of chemical additions might conceivably be of importance. Results obtained on a number of series where lime was added prior to the ferric iron coagulant, and other series where iron coagulant was added before pH adjustment, are graphically shown in Fig. 4. The sequence of coagulant addition appears to be of little significance under these conditions. However, this does not mean that the sequence of addition does not play a role with different types of sewages and with different pH ad-

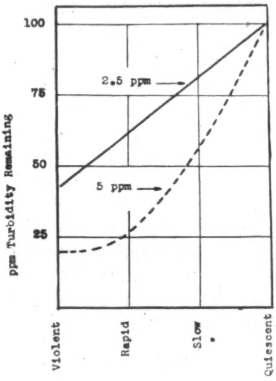

Fig. 3.—Effect of pH adjustment with lime before coagulant addition.

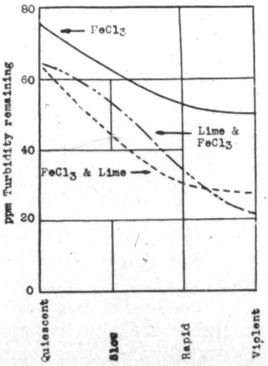

Fig. 4.—Effect of mixing on clarification with ferric chloride alone, and pH adjustment before and after coagulant addition.

justments. The conditions presented here are limited to a definite quantity of coagulant and optimum pH on the alkaline side. The question of the order of coagulant addition at different pH values and with different sewages will be discussed in another paper.

The degree and rate of mixing has no effect upon the final pH of the resulting mixture, when lime or sulphuric acid are used for pH adjustment. In Table I results are compared with violent and slow mixing.

TABLE I.—*Comparison of Rate of Mixing on Final pH Values*

Chemical	Mg./L.	Final pH Violent Mixing	Final pH Quiescent, Slowly Stirred
H_2SO_4	3050	1.5	1.5
	610	2.5	2.5
	280	3.5	3.5
	180	4.5	4.5
	136	5.5	5.5
	32	6.5	6.5
$Ca(OH)_2$	11	7.5	7.5
	92	8.5	8.5
	334	9.5	9.5

Even with the lowest quantities of chemicals added for adjustment no variation in final pH could be determined by the ordinary colorimetric method. It is clear, therefore, that if a localized effect takes place it appears to be for practical purposes stoichiometric and when an excess of the chemical remains localized it is unchanged until mixing or diffusion causes it to be distributed. This fact is of interest in connection with the desirability of proper pH adjustment. Although thorough mixing of chemicals used for pH adjustment is desirable, the mixing need not be immediate and the rapidity of mixing is not so important a factor as with iron coagulants. When mixing of the coagulant is deficient, or mixing is not properly applied, unsatisfactory coagulation takes place or larger quantities of coagulants are required to produce the same degree of clarification as when mixing is good. Since there is considerable leeway, proper pH adjustment can be accomplished before the coagulant is added, without difficulty and loss of coagulant.

FLOCCULATION

For the formation of a floc of sufficient size of particles to afford rapid settling, the chemically treated sewage must be agitated in such a manner that the particles are brought in contact with one another and prevented from subsiding. The more common methods employed for this procedure are the application of bubbles of diffused air, paddles, or the combination of air and paddles.

The devices employed in the experimental work consisted of: (1) diffused aeration, (2) Dorr horizontal paddle type of flocculator, (3) vertical propeller type stirring machine described previously.[7] Unless otherwise stated results reported were obtained in the laboratory with the vertical propeller type of flocculator.

Flocculation Time and Dosage.—Slow stirring of settled sewage at a flocculating speed of 15 to 22 r.p.m. accomplished a certain amount of coagulation. This floc formation for practical purposes was completed in 1 to 1.5 hours. The effect of time and stirring alone, on sewage previously settled for two hours, is graphically shown in Fig. 5.

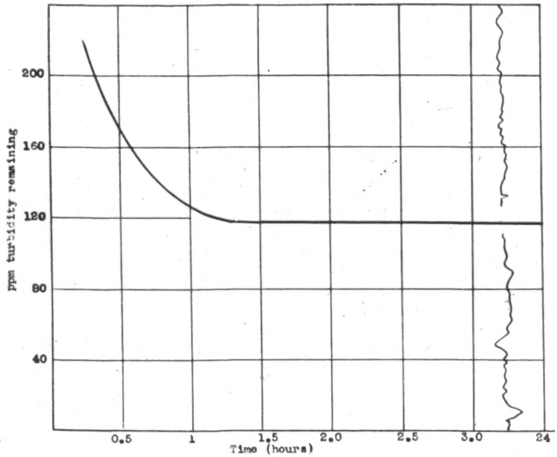

FIG. 5.—Effect of time of flocculation on coagulation without chemicals.

Although from 40 to 50 per cent of the remaining turbidity can be removed by flocculating for about one hour, the turbidity remaining is appreciable and can not be removed even if flocculation is continued for a period of 24 hours. Nevertheless, flocculating alone produces an appreciable clarification and may be of practical interest when greater removal than that caused by settling is required, or when, temporarily, no chemicals are available. In gauging the effect of chemicals on clarification the clarification caused by flocculation alone should be taken into consideration.

The relation between flocculation time and coagulant dosage is shown in Fig. 6, where the results obtained with different dosages of ferric chloride and varying flocculation periods are given. It is evident that the nearer the chemical dosage approaches the amount of coagulant necessary to produce maximum clarification, the smaller the effect of flocculation time. This is more clearly shown in Fig. 7, where the percentage of turbidity ultimately removed is plotted for a number of different chemical dosages. A flocculation time of from 15 to 30 minutes, with an adequate chemical dose, is for practical purposes sufficient to obtain maximum clarification. Most of the work is accomplished in the first 15 minutes, but more economical dosages can be used when the coagulation time is increased. For instance, a dosage of 20 p.p.m. Fe as ferric chloride can be reduced by half, when two hours coagulation is given instead of 15 minutes. Reduction of coagulant from 30 to 20 p.p.m. iron can be obtained by increasing the flocculation time from 15 to 25 minutes. With coagulant dosages sufficient for the formation of a proper floc, a too rapid flow through the flocculation tank is undesirable; but on the other hand long periods of flocculation are of little value, because the additional clarification is small. On the other hand when coagulant and chemical dosages applied are too low for maximum clarification at short coagulation and flocculation periods, the removal of turbidity can be increased by lengthening the flocculation time.

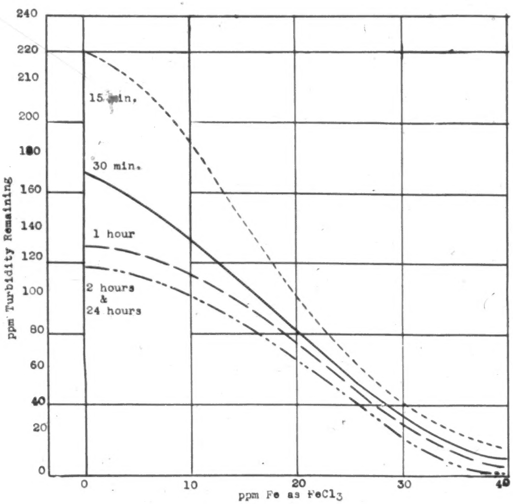

Fig. 6.—Relation between flocculation time and chemical dosage.

The results reported as illustrations were obtained with samples of a rather strong, stale sewage. With weaker and fresher sewages the general relationships remain the same, although the differences may be smaller.

Type of Flocculator.—The mechanical flocculators used were of two types, namely a swirling propeller and a horizontal paddle machine. In order to determine the effect of these two types of flocculators on floc formation and clarification the speed was kept constant at 16 r.p.m. The paddles in both machines were of approximately the same size, so that the peripheral velocity was similar. In each case the velocity was sufficient to keep the floc in suspension. Results on the same samples of sewage are illustrated in Fig. 8 for the first 30 minutes of flocculation. The turbidity remaining after 5 minutes flocculation was slightly greater in the propeller flocculator, the difference increasing during the first 15 minutes and slightly decreasing thereafter. Although the difference is not great it was definitely in favor of the horizontal type.

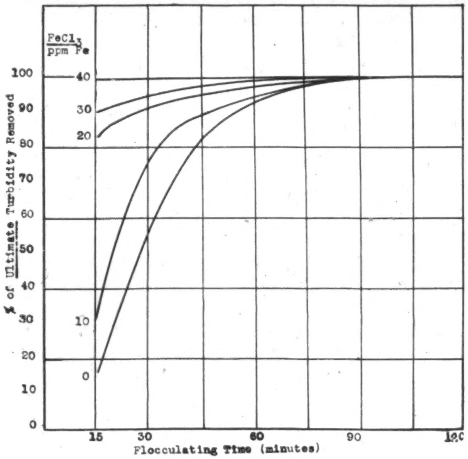

FIG. 7.—Comparison of percentage turbidity removal at different flocculation times and varying chemical dosages.

The example chosen for illustration concerned a stale strong sewage requiring a dosage of 25 p.p.m. Fe as $FeCl_3$ for optimum coagulation. The coagulant dosage employed was the same for both flocculators.

For comparison with air as stirring agent the horizontal paddle

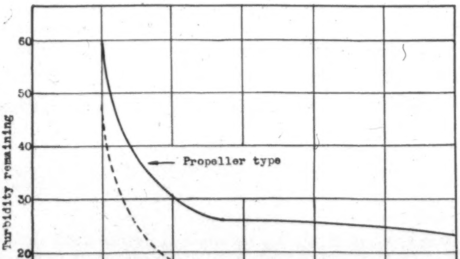

FIG. 8.—Comparison of propeller and horizontal paddle types of flocculation (at 16 r.p.m.).

type was chosen. A small spiral-flow diffused air tank was employed for aeration, and the amount of air used was just sufficient to keep the floc in suspension. The quantities of air used amounted to 0.24 cu. ft. per gallon in 30 minutes flocculation time. The paddles were rotated at 16 r.p.m. Results on stale sewage, with turbidities of about 220 p.p.m. after 2 hours settling, are shown for different time intervals in Fig. 9. When no coagulant was used the effect of air on the rate and degree of clarification was the same as for horizontal paddles. With smaller quantities of coagulant little difference was observed; to produce almost complete clarification, diffused air produced floc more rapidly than paddles, with better settling qualities. As an illustration, a series of results are shown in Table II. The persistent small differences observed with lower and intermediate dosages have some significance in respect to floc formation. Under these conditions the floc formed is weak, and it breaks up more readily when sufficient air is supplied to keep the mass in motion than when paddles are used for this purpose. With sufficient coagulant the floc formed is resistant and even stronger aeration does not cause dispersion. For the same co-

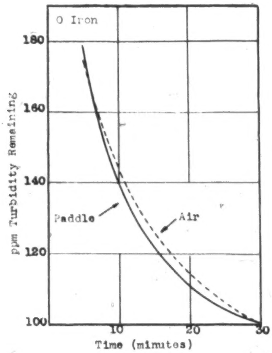

FIG. 9.—Comparison of air and horizontal paddle flocculation, without coagulants.

TABLE II.—*Comparison of Air and Paddles for Flocculation (P.p.m. Turbidity Remaining)*

P.p.m. Fe		10		15		20	
Time Min.	Cu. Ft. Air per Gal.	Paddles	Air	Paddles	Air	Paddles	Air
5	0.04	74	75	58	58	42	24
10	0.08	55	60	41	42	33	13
15	0.12	46	52	28	35	14	10
30	0.24	42	45	22	26	10	8

agulant dosages no differences in size or general appearance of the floc formed was noticeable between the two methods.

With smaller dosages of iron coagulant (5 p.p.m. Fe) and optimum pH adjustment with lime, diffused aeration for short periods of flocculation gave better results than the paddles. However, with short periods of flocculation (less than 15 minutes) the turbidity removals were not satisfactory as compared with the ultimate removals obtained in 30 minutes of flocculation. When 20 or more minutes of flocculation were used the paddles proved better than aeration. The quantities of air used were the same as those with iron coagulant alone. It is apparent, therefore, that under these conditions more rapid flocculation can be accomplished with air, but in order to produce equal clarification

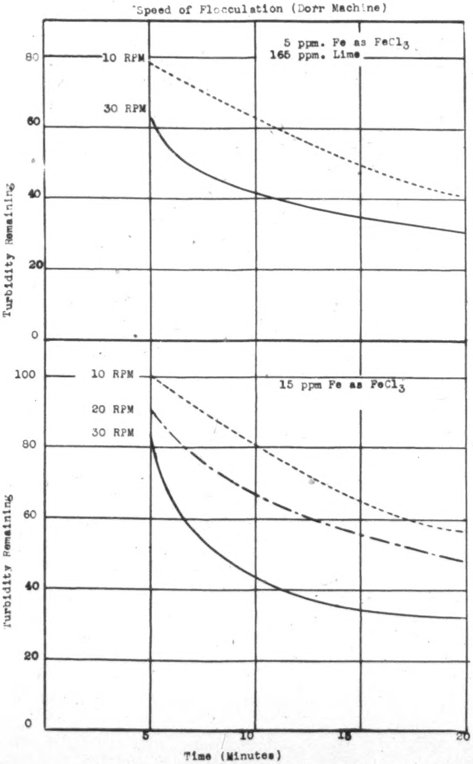

FIG. 10.—Effect of speed of flocculators on clarification with and without lime for pH adjustment.

somewhat larger dosages of coagulant are necessary to prevent breaking up of the floc. In order to prevent breaking up of the floc the air supply must be low and carefully controlled, as well as the period of flocculation.

Velocity of Paddles.—The effect of the velocity of paddle rotation in respect to the resultant clarification was studied, both with iron coagulant alone and iron-lime treatment. The experiments were performed with the horizontal as well as propeller type of flocculators. The speed limit of the horizontal type of flocculator was 30 r.p.m. Some results on the horizontal paddle machine, with different quantities of iron salt and varying periods of flocculation, together with results on lime and iron salt treatment, are shown in Fig. 10. The results show that more rapid and more complete removals were obtained with both types of treatment when the maximum speed was used. At the low speed scum formation occurred, which was absent at the high speed, probably because of a better inclusion of the grease in the heavier floc particles. At the higher speed less fine non-settleable floc was present in the effluents. The floc produced at higher speeds of rotation settled more rapidly than at the lower speeds.

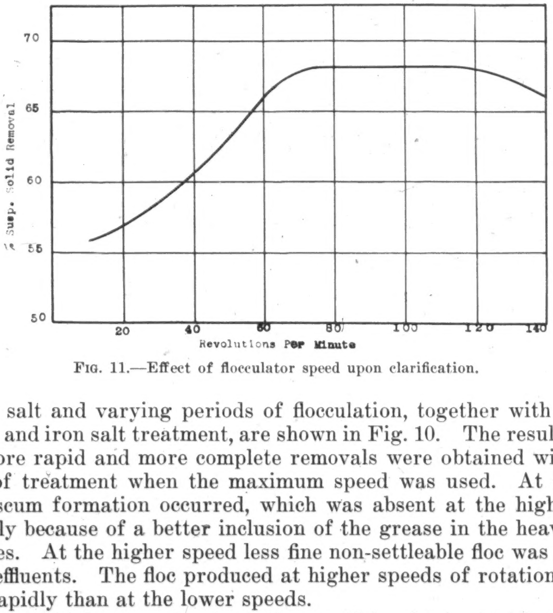

FIG. 11.—Effect of flocculator speed upon clarification.

Since no higher speeds of rotation could be obtained with the horizontal paddle type of flocculator, the propeller type, allowing speeds up to 176 r.p.m., was used for further study on the effect of paddle velocity. The results obtained over a range of speeds of rotation varying from 11 to 176 r.p.m., with constant periods of flocculation of 20 minutes, and constant quantity of 15 p.p.m. Fe as $FeCl_3$, are graphically shown in Fig. 11. The percentage suspended solids reduction of previously settled, rather strong sewage (310 to 320 p.p.m. suspended solids) increased gradually up to about 70 r.p.m. Greater speeds of rotation did not increase the subsequent percentage suspended solids removal, and at high speeds the clarification decreased. The example given in Fig. 11 deals with incomplete clarification, due to insufficient coagulant dosages. Under these conditions rotary speeds up to 60 r.p.m. caused a reduction in finely divided suspended matter of 67 per cent as compared with 56 per cent turbidity removal at 16 r.p.m., or expressed in parts per million, a greater removal of 25 parts non-settleable material. Although these increased removals are not great, they are appreciable, and significant. With the increase in speed of rotation the cost of power increases and it would be a question whether similar removals could not be accomplished more cheaply with increased dosages of chemicals. This is especially the case when weak and fresh sewages requiring comparatively low coagulant dosages are encountered. With higher degrees of clarification the effect of speed of the flocculator is still substantial, due to the fact that more rapid movement effects a greater contact of floc with the finely divided, pseudo-colloidal and colloidal particles present. Of considerable interest was the fact that even at high speeds (up to 120 r.p.m.) the floc formed did not disintegrate or break up into smaller particles. Usually, when insufficient coagulant is used for complete clarification, the floc formed is weaker for the same sewage than if the optimum dosage is applied.

The action of a propeller type agitator, producing a swirling motion, is different from the violent agitation caused by air blowing, baffle mixers and drop-off weirs, which our experience has shown to be much more active in dispersing the floc formed. The movement of horizontal paddles through the liquid is similar to the swirling motion produced by a propeller flocculator, so that the practice of using paddle type flocculators appears to be well grounded and in general superior to air agitation.

Effect of Settleable Solids Concentration

It was thought possible that clarification could be increased by the presence of increasing quantities of settleable solids. This would be the case if the settleable solids particles were necessary as nuclei. Accordingly, experiments were conducted with variable quantities of settleable suspended solids present and with varying speeds of flocculation. The results obtained on three different suspended solids concentrations at two different speeds of flocculation are shown in Fig. 12. The suspended solids were varied by settling and decanting in the manner described previously.[8] The sewage samples used contained 130, 250 and 690 p.p.m. turbidity. These samples were treated with 15 p.p.m. Fe as $FeCl_3$ and flocculated for different periods.

The concentration of settleable suspended solids appeared to have little, if any, effect upon the required time of flocculation. This is in accord with results previously presented on the effect of increased suspended solids concentration upon increased turbidity removals.[8] There was also no noticeable effect of the increased suspended solids concentration upon turbidity removals, when the speed of flocculation was increased. The effect of increased speed of flocculation for all suspended solids concentration tried was similar to those reported above (Fig. 10), where the effect of velocity was discussed. The results given in Figs. 10 and 12 are comparable as far as type of horizontal paddle flocculator is concerned, but differ in regard to sewage, rotation and (in part) chemical dosage. Nevertheless, the same relative results are obtained with varying speeds of flocculator.

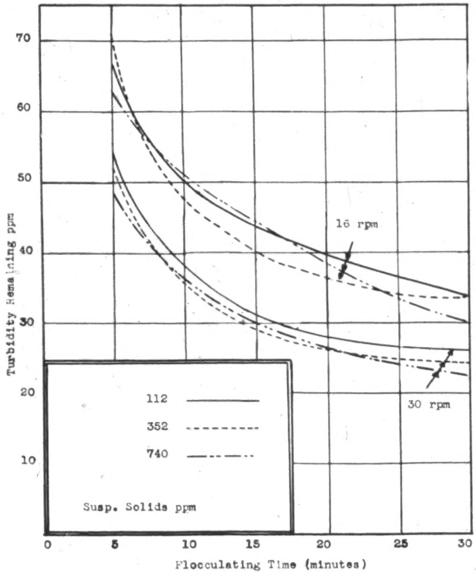

FIG. 12.—Effect of settleable solids concentration upon clarification.

DISCUSSION

In order to obtain best results with ferric coagulants, either with or without the use of lime, rapid mixing during addition of the iron salt is essential. It is immaterial whether the lime for pH adjustment is added before or after the iron dosage, flash mixing is necessary to produce best results with the lowest quantities of coagulant. The reason for the necessity of rapid mixing is that the coagulant must be distributed as quickly as possible throughout the mass of the liquid to prevent localized hydrolysis. With improper introduction and distribution of the coagulant the localized concentration of the salt is utilized and a portion of the liquid remains untreated. It is clear therefore, that the requirements for water coagulation, rapid and complete mixing, are also necessary for sewage coagulation.

When proper mixing is employed, our results do not show any danger of indifferent coagulation on account of reduction of iron in ferric salts to the ferrous condition, so that aeration is not essential during flocculation, to prevent reduction. As a matter of fact, when sufficient air was used to keep the mass in motion, paddle flocculation was in general superior. However, with air flocculation the formation of floc was more rapid and the time could be reduced somewhat. At the same time when the type of mixing device is inadequate for rapid and through distribution of the coagulant, aeration undoubtedly will be beneficial.

The chemicals used for pH adjustment can be added before or after the coagulant, but in general, when lime is added before the coagulant, the rate of mixing can be slightly reduced to obtain equal results as when coagulant is added before the lime. The presence of trade waste in sewage, other unusual conditions, or pH adjustment on the acid side may make it desirable to change the procedure. This question is of sufficient interest to be treated in more detail.

From our studies it appears that the flocculation time required will vary somewhat from place to place depending upon the type of sewage. The effect of coagulant dosage upon the flocculation time is far more important. In general the time of flocculation required is dependent upon the quantity of coagulant added. With dosages approaching the optimum for complete coagulation, from 15 to 30 minutes flocculation is sufficient. With less than 15 minutes flocculation after mixing, the subsequent suspended solids removals decrease. These results are in general in accord with the findings of other investigators.

Of interest are the findings that higher speeds of paddle and propeller flocculators produced better clarification. It has been thought that higher speeds would break up the floc formed, leaving considerable poorly settling, small, particles in the effluent. The fact that, with higher speeds of rotation the swirling motion affected scum formation, is perhaps of particular interest where considerable quantities of greasy substances are present. The embedding of these grease materials in the floc did not appear to affect the settling qualities of the floc formed.

In dealing with cotton filtered sewages, it has been observed that a good floc can be obtained with the proper dosage of coagulant and required time of flocculation. The addition of coarse material does not increase the rate or degree of clarification. Nevertheless, with increasing quantities of finely divided suspended material, floc formation is better. It appears that either the floc formed from finely divided suspended material has a greater power of adsorbing other particles during the flocculation process, or that on flocculation, separate, distinct flocs are formed from the remaining fine suspended particles. This question will be discussed in a following paper dealing with the iron demand of sewages.

SUMMARY

Experiments were made to evaluate some types of mixing and flocculation methods used for sewage coagulation. The effect of the velocity of mixing coagulants with sewage, and speed of agitation during flocculation, on the floc formation and subsequent clarification, using different coagulating salts and pH adjustment, the manner of introduction of chemicals, as well as the effect of settlable solids concentration were studied. It was found that to obtain best results with ferric coagulants, either with or without lime, rapid initial mixing during addition of the chemicals is essential. The flocculation time required is dependent upon the coagulant dosage and to some degree upon the type of sewage. With proper mixing, optimum chemical dosage and slow flocculation, complete coagulation can be accomplished in from 15 to 30 minutes. With dosages of coagulant sufficient to produce nearly complete clarification diffused air flocculation was more rapid, but with smaller dosages little difference was observed between the horizontal paddle type flocculator operated at slow or rapid speeds and aeration. In general air flocculation was inferior. At equal speeds of flocculation the horizontal paddle type produced better results than the propeller type of flocculator. Flocculating speeds much higher than normally used were found to give better subsequent clarification. With higher speeds no scum formation occurred with the swirling propeller type of flocculator, grease was embedded and the floc was not disintegrated. The concentration of settleable solids was not a factor in determining the time or speed of flocculation.

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OXIDATION OF SEWAGE BY ACTIVATED SLUDGE

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It is quite natural that the rate of biochemical oxidation of dilute sewage mixtures, which has been carefully studied,[1, 2] should be assumed to hold for the biological oxidation devices, such as the activated sludge process. The lack of experimental evidence to the contrary and the fact that the oxygen demand of the sludge itself, excepting the first day, conforms fairly well with the established rates for sewage mixtures has doubtless contributed to this view. The general conception of the activated sludge process is that there is a rapid adsorption of organic matter by the sludge and that the adsorbed material is then oxidized biochemically at a rate approximating that observed for a polluted water or sewage mixture.

The conditions under which the organic matter is oxidized in the activated sludge treatment plant and in a bottle are quite different. Under the conditions of the biochemical oxygen demand test, the bacteria are relatively few at the start and multiply until a limiting number is reached. In the activated sludge process, the sewage is added to a material where many bacteria are concentrated in the zoogleal masses,[3] so that the number of bacteria present per unit volume far exceeds that which is ordinarily reached. The activated sludge floc can be considered a bacterial colony in liquid media. Thus a solution containing enough of the dispersed zoogleal bacteria to give it a milky appearance will produce only a small amount of floc, so that with a solution containing 1,000 p.p.m. of floc, there are so many bacteria concentrated in the floc that the actual number present far exceeds that ever observed in the dispersed condition. Under these conditions it is reasonable to suppose that the organic matter might be oxidized at an accelerated rate. Likewise, it might be inferred that slow growing bacterial species, such as nitrifying organisms, would require more time to accomplish a given amount of work than the more active species which utilize carbonaceous materials under the conditions imposed by the biochemical oxygen demand test, where two definite stages of oxidation are observed. With activated sludge, it may take three weeks to build up an actively nitrifying variety. Once the organisms are present in sufficient numbers, they should oxidize ammonia from the start and the two stages observed under the former condition might proceed simultaneously in the activated sludge tanks, it being understood that the ammonia formed from the decomposition of nitrogenous substances must necessarily be released before it can be utilized. A study of the oxidation of sewage in the presence of activated sludge would furnish valuable information on these possibilities.

The work done along these lines has dealt with the oxygen demand of the sludge-sewage mixtures. Grant, Hurwitz, and Mohlman[4] computed a value for the oxygen demand of sewage in the presence of activated sludge by treating sewage with varying amounts of activated sludge, determining the oxygen demand and deducting the average oxygen demand value of the sludge from the observed values for sludge plus sewage. They obtained a negative oxygen demand for sewage in the presence of 4,740 p.p.m. of sludge, the difference being within the limits of experimental error. With decreasing amounts of sludge, they observed increasing oxygen demands for the sewage. The maximum oxygen demand was 10 p.p.m. in 2 hours in the presence of 920 p.p.m. of sludge. Recently Kessler and Nichols[5] have shown that the rate of utilization of oxygen by activated sludge plus sewage drops rapidly the first few hours. They found that on treating activated sludge with sewage, the mixture used up oxygen at the rate of 54 p.p.m. of oxygen per hour during the first hour (computed from 6-minute tests) and that this figure dropped rapidly so that after 3 hours of aeration the mixture was using oxygen at the rate of 20 p.p.m. per hour. Unless this sewage contained unusual amounts of substances capable of reacting directly with dissolved oxygen this would indicate a very rapid biological oxidation of the sewage.

At the London School of Hygiene, experiments under the direction of Prof. W. W. C. Topley[8] indicated that "the rate of oxidation of a mixture of crude sewage and activated sludge is much greater than the sum of the rates for the constituents treated separately." The oxygen adsorption was measured by a modified Barcroft respirometer. "The respirometer consists of two glass flasks of about the same volume (35 to 40 ml.), connected one on each side of a differential manometer." The apparatus is calibrated so that the manometer readings serve as a measure of oxygen removal and the carbon dioxide is adsorbed in a small inner tube which contains a 10 per cent aqueous solution of potassium hydroxide. The results of a group of experiments are given in Table 7 of the "Report of the Water Pollution Research Board for the Year Ended 30th June, 1935" and are presented here as Table I. These workers concluded "that by mixing crude sewage and activated sludge the rates of oxidation of the sewage or sludge or both by air are greatly accelerated." In similar experiments they found that effluents likewise used oxygen more rapidly in the presence of sludge than in its absence.

METHOD FOR THE DETERMINATION OF THE OXYGEN DEMAND OF SEWAGE IN THE PRESENCE OF ACTIVATED SLUDGE

The apparatus described by Theriault and McNamee[6] was used for the study of the oxidation of sewage in the presence of activated sludge. In this apparatus a measured volume of the sludge-sewage mixture is placed in a bottle where the air above the liquid is recirculated through the liquid in a closed system. Ten ml. samples of the air are removed for analysis at definite time intervals. By using a modified Winkler procedure for determining the oxygen, the oxygen content of a milli-

TABLE I.*—*Absorption of Oxygen from Air at 22° C. by Crude Sewage, Activated Sludge, and Mixtures of Sewage and Sludge*

Oxygen in Cubic Millimeters at 0° C. and 760 mm.
W = water; C.S. = crude sewage; S.L. = activated sludge.

Contents of Barcroft Flasks		Period in Hours					
Left Hand Flask	Right Hand Flask	1	2	3	4	5	6
A. 3 ml. W.	2 ml. C.S. + 1 ml. W.	16	32	46	49	55	60
B. 3 ml. W.	1 ml. S.L. + 2 ml. W.	51	97	137	175	204	227
C. 3 ml. W.	1 ml. S.L. + 2 ml. C.S.	116	229	336	446	532	605
D. 1 ml. S.L. + 2 ml. W.	1 ml. S.L. + 2 ml. C.S.	81	148	210	279	325	391
E. 2 ml. C.S. + 1 ml. W.	2 ml. C.S. + 1 ml. S.L.	102	211	305	408	484	555
A + B		67	129	183	224	259	287
C − (A + B)		49	100	153	222	273	318
E − B		51	114	168	233	280	328
D − A		65	116	164	230	270	331

* Table 7 of "Report of the Water Pollution Research Board for the Year Ended 30th June, 1935."

liter of air, expressed in milligrams, can be measured accurately to the fourth decimal place. For the present study, two bottles were used. The one bottle contained a liter of sludge with its supernatant. The other bottle contained a liter of sludge which was allowed to settle and the supernatant replaced by sewage. The oxygen demand of the sludge-sewage mixture, plus the oxygen demand of the removed supernatant, represents the sum of the oxygen demands of a liter of the sludge and of the sewage. The value for the oxygen demand of a liter of sludge is subtracted from the above value to obtain the oxygen demand of the added sewage. The oxygen demand of the supernatant is relatively small and could be neglected without doing serious damage to the results. This method was used in order to have the same amount of sludge present in each liter of solution.

OXIDATION OF SEWAGE BY "GOOD" ACTIVATED SLUDGE

The sludge used in Series 1 had all the characteristics of "good" activated sludge. The sludge was from the North sewage treatment plant of Lancaster, Pennsylvania. In other experiments it was found that this sludge removed from 75 to 90 per cent (based on the first stage biochemical oxygen demand) of the oxidizable matter from sewage in a period of 30 minutes. The sludge was actively nitrifying and settled readily, leaving a clear supernatant. Prior to the start of the experiment, the sludge was treated with sewage and aerated for 18 hours. The suspended matter content was 4,396 p.p.m. Two one-liter portions of this sludge were used in the experiment. The one portion was placed in an aeration bottle without further treatment. The other liter was placed in a cylinder, allowed to settle, 700 ml. of the supernatant siphoned off and the volume of the settled sludge was then made up to one liter by the addition of 700 ml. of sewage, which had been filtered through cotton. At the start of the experiment, the pH of the sludge was 7.35 and of the sludge-sewage mixture, 8.40. The biochemical oxygen demands of the supernatant and the filtered sewage were determined by the dilution method; the values are presented in Table II and Figure 1, where the time is plotted in days.

TABLE II.—*Oxygen Demand (Dilution Method) of Sewage and Supernatant*

Days Incubated	Series 1		Series 2		Series 3	
	Sewage	Supernatant	Sewage	Supernatant	Sewage	Supernatant
	Oxygen Demand, p.p.m.					
1	107	5.6			87.5	16.8
2					166.5	23.2
3			216	12.8	240.0	40.2
4	224	19.0				
5					257.5	44.0
6			267	14.2		
7	244	23.0				
8			297	21.6		
14	442	34.0	451	27.6		

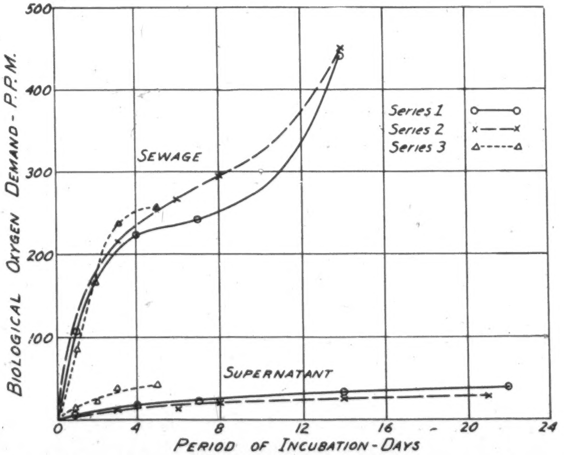

FIG. 1.—Biological oxygen demand of sewage and supernatant obtained by the dilution method.

The temperature of the sludge and sewage was adjusted to 20° C. and the experiment was conducted in a 20° C. incubator. The data of Series 1, 2 and 3 are given in Table III. The results of Series 1 are presented in Figure 2. This series was discontinued after 24 hours. The sludges from the two bottles were composited and 50 ml. of phosphate buffer (pH 7.2) added. The sludge was again divided into equal parts and used in a similar experiment called Series 2. The pH of the sludge used in Series 2 was 7.22 and the sludge-sewage mixture 7.25. Owing to the poorer settling quality of the sludge, only 600 ml. of supernatant was replaced by sewage in Series 2. The biochemical oxygen demand values obtained in Series 2 are given in Figure 3.

TABLE III.—*Observed Oxygen Demands of Sludge and Sludge-Sewage Mixtures*

Time in Hours	Series 1			Series 2			Series 3		
	Sludge with 700 ml. Supernatant Replaced by Sewage = A	Sludge = B	A − B	Sludge with 600 ml. Supernatant Replaced by Sewage = A	Sludge = B	A − B	Sludge with 700 ml. Supernatant Replaced by Sewage = A	Sludge = B	A − B
	Oxygen Demand, p.p.m.								
0.5	55.0	14.5	40.5	42.2	15.7	26.5	31.3	5.5	25.8
1.5	116.9	28.6	88.3						
2.0				116.3	49.4	66.9	87.8	24.3	63.5
3.0	196.0	56.5	139.5	161.0	61.6	99.4	112.8	32.1	80.7
4.0				197.6	75.7	121.9			
4.5							151.9	50.6	101.3
5.0	287.0	87.6	199.4						
5.5				234.2	102.9	131.3			
7.0				250.7	117.6	133.1			
10.0	367.0	172.9	194.1				245.0	104.9	140.1
20.0				390.7	269.7	121.0			
24.0	529.4	367.4	162.0				384.2	230.3	153.9

In order to obtain the oxygen demand of the sewage, a correction is applied for the oxygen demand of the supernatant which was removed from the one portion. The one-day oxygen demand of the supernatant removed from Series 1 was found, by the dilution method, to be 5.6 p.p.m. This would give a correction of 0.16 p.p.m. $\{5.6 \times [700/(1000 \times 24)]\}$ per hour. Since the supernatant had been in contact with the sludge for 18 hours and since the sludge curve does not break sharply, this correction is distributed evenly over the 24-hour period. The negative slope of part of the curve A — B in Series 1 and 2 indicates a much higher demand of the supernatant. In view of the fact that the sewage was oxidized much more rapidly in the presence of sludge, it appears that the supernatant also is oxidized more rapidly when sludge is present. This conclusion was also reached by the workers at the London School of Hygiene. The corrections for the oxygen demand of the supernatants were, therefore, based on the 14-day oxygen demand rather than the one-day value. This amounts to a correction of approximately 1.0 p.p.m. per hour. This correction raised the 20-hour oxygen demand value of the sewage enough to remove the negative slope from the graph of the values observed in Series 2. It did not, however, raise the 24-hour oxygen demand value of the sewage

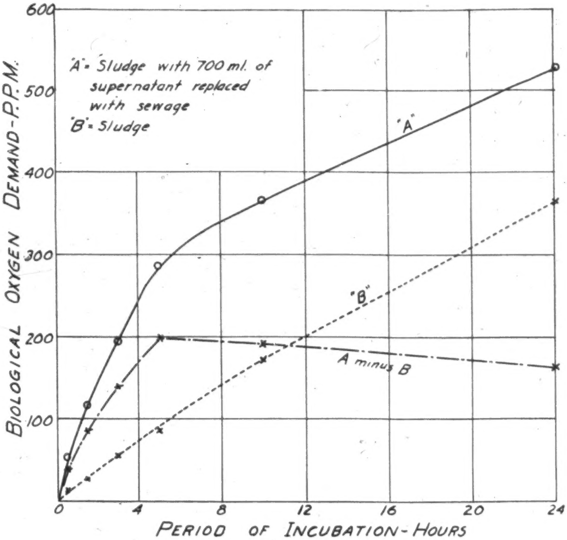

Fig. 2.—Series 1. Biological oxygen demand of sludge and sludge-sewage mixture obtained by the aeration method.

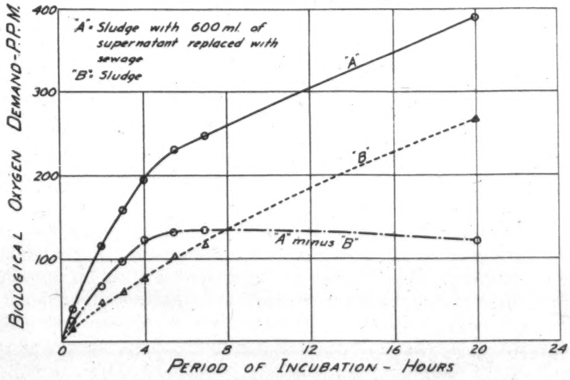

Fig. 3.—Series 2. Biological oxygen demand of sludge and sludge-sewage mixture obtained by the aeration method.

in Series 1 enough to bring it in line. The difference in pH of the sludges in Series 1 may account for this discrepancy. The oxygen demand values of the sewages in the presence of activated sludge, plotted in Figure 4, were obtained from the corrected A — B curves and represent the milligrams of oxygen utilized by one liter of the sewage.

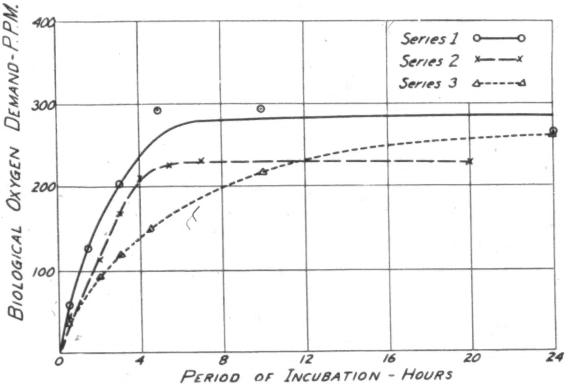

FIG. 4.—Oxidation of sewage in the presence of activated sludge.

The oxidation of the sewage in the presence of activated sludge is much more rapid than the oxidation which takes place under the conditions of the biological oxygen demand test. It is to be remembered that the sewage used in these experiments was freed from large suspended particles by filtration through cotton so that the rates observed are for the oxidizable matter in solution or in a colloidal state. In the presence of "good" activated sludge, Series 1 and 2, the oxidation of the sewage by the activated sludge was practically completed in 5 hours. That is, after 5 hours the curve for the oxidation of sewage in the presence of activated sludge ceased to rise. In Series 1, the 5-hour oxygen demand of the sewage in the presence of activatd sludge has the same value as the 240-hour oxygen demand of the same sewage as determined by the dilution method and is more than the total first stage demand. In the presence of activated sludge, 24 per cent of the 7-day biological oxygen demand was satisfied in 30 minutes, 54 per cent in 1.5 hours, 83 per cent in 3 hours and 119 per cent in 5 hours. Compared to the 14-day oxygen demand obtained by the dilution method, the sewage in Series 1 was 63 per cent oxidized and that of Series 2 about 50 per cent oxidized. This probably indicates that the end products of the dilution method are different from those produced by the activated sludge and the higher state of oxidation would be reached only with the decomposition of the activated sludge floc.

Oxidation of Sewage by "Poor" Activated Sludge

The oxidation of sewage in the presence of "poor" activated sludge is shown in the graphs marked Series 3 (Fig. 5). The sludge used in this series was taken from the aeration tank of a small experimental activated sludge plant which had been in operation only a few weeks. The temperature in the aeration tank was 6° C. and the suspended matter content of the tank was below 1,000 p.p.m. The sludge settled very poorly and the supernatant was loaded with finely dispersed particles which gave it a marked turbidity. The sludge was concentrated by settling and the suspended matter content of the mixtures in Series 3 was 2,720 p.p.m. Seven hundred ml. of sewage were used in this experiment. This sludge was not nitrifying. The nitrite content of the mixture increased from 0.4 to 0.5 p.p.m. in the 24 hours that the mixture was aerated. The nitrate content remained constant at 0.5 p.p.m. The sewage and supernatant in the dilution bottles started to nitrify on the fifth day. For this reason the correction for supernatant is based on the 5-day oxygen demand. With this particular sludge, more time was required for the oxidation of the sewage so that considerable oxidation was noted between the 10th and 24th hour. In spite of the fact that this can be considered a poor activated sludge, the sewage was oxidized much more rapidly in its presence. The percentage of the 5 day B.O.D. satisfied in 0.5, 2, 3, 4.5, 10 and 24 hours was 14.6, 36.6, 46.9, 59.3, 84.7 and 102.5 respectively. That is, in the presence of the activated sludge, the oxygen adsorbed by sewage was greater in one day than the 5-day oxygen demand, determined by the dilution method, of the same sewage.

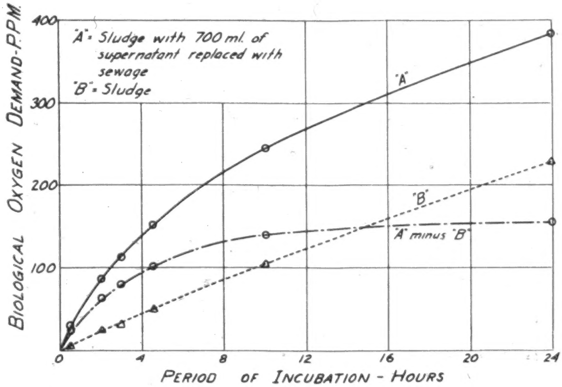

Fig. 5.—Series 3. Biological oxygen demand of sludge and sludge-sewage mixture obtained by the aeration method.

The term "poor" refers to the physical property of the sludge and not to its oxidizing capacity. On a per gram of sludge basis, the percentage of the 5-day oxygen demand of the sewage satisfied in a given time by the sludge of Series 3 is not much different from that observed from Series 1 and 2.

	Time (Hours)		
	0.5	3.0	10
	Per cent of 5-day oxygen demand of sewage satisfied per gram of sludge		
Series 1	5.8	20.1	29.0
Series 2	4.1	15.5	20.9
Series 3	5.3	17.2	31.1

RATE OF OXIDATION

The deoxygenation constant k observed in this group of experiments is much larger than that observed for polluted water. The unimolecular equation $Y = L(1-10^{-kt})$ does not fit the observed values for the oxidation of sewage in the presence of activated sludge of Series 1 and 2 very satisfactorily. This is to be expected if nitrification is in progress. Using the statistical treatment method of Reed and Theriault[7] for determining the k value, k (when t is expressed in days) for Series 1 was found to be 2.009 and for Series 2, 1.992. The same k value (2.0) gave values for Series 3 which were in good agreement with the observed values. The k value of 2.0 may be compared with the value of 0.1 observed for river water. It is significant that this is practically the same k value (2.0) as was deduced by Theriault[6] from the mathematical analysis of a single sludge oxidation curve. He concluded that the curve was the resultant of two curves, one representing a rapid oxidation and the other a much slower oxidation. This rapid oxidation was attributed to a purely chemical or enzymatic effect by Theriault and McNamee.[6] The sludge used in these experiments was taken from the bottom of a channel and it is probable that it contained reduced substances capable of reacting with dissolved oxygen. However, in the light of the present experiment, it is probable that the greater part of this "immediate" oxygen demand resulted from the oxidation of the organic matter present in the sludge liquor. No attempt has been made in the present experiment to study the mechanism of the oxidation process. This rapid oxidation may or may not be enzymatic.

SUMMARY

The soluble and colloidal matter of sewage is oxidized much more rapidly than has generally been realized. "Good" activated sludge can dispose of the greater part of the oxidizable substances in a period of 5 hours, less efficient activated sludge may require a much longer time. In the presence of nitrifying activated sludge, the 5-hour oxygen demand of the sewage may be greater than the total first stage oxygen demand. The total oxygen demand of the sewage in the presence of activated sludge is lower than the total oxygen demand observed under the conditions of the biochemical oxygen demand test, which probably means that a considerable amount of the material is used to synthesize activated sludge flocs. If this be the case, then strictly speaking, the sewage cannot be considered completely oxidized until the sludge itself is disintegrated by other organisms. If nitrification is occurring, the rate of oxidation of the sewage in the presence of activated sludge cannot be expressed very satisfactorily by the unimolecular equation. Compared to the k value of 0.1 observed for river water, the k value observed for sewage in the presence of activated sludge is about 2.0. It is concluded that a large part of the oxidation required for the stabilization of the oxidizable substances present in sewage occurs during the first few hours of contact with "good" activated sludge.

ACKNOWLEDGMENTS

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THE DETERMINATION OF SULPHIDES IN SEWAGE

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An investigation has been carried out at the laboratory of the Los Angeles County Sanitation Districts to establish the relative merits of certain methods for determining sulphides in sewage. The study has not aimed at an exhaustive survey of all procedures which have from time to time been suggested; rather, attention is confined to modifications of the iodine method, to the antimony method, to a few tests of a lead method, and to a method, which, while old, has not heretofore been generally applied to sewage analysis. The outstanding result of the research has been the discovery that this latter method can, with suitable modifications, provide a highly satisfactory tool for the simple, rapid, and fairly accurate determination of sulphides in sewage.

The methods investigated have been considered from the standpoint of their serviceability for determining the total sulphide content of sewage. A subsequent section deals with the problem of distinguishing the principal forms in which the sulphides may exist.

Iodine Methods

The designation ''iodine methods'' may be taken to include a group of modified procedures, differing widely in detail but having this in common, that the sulphide determination ultimately depends upon a titration with standard iodine solution.

Two modifications were investigated. The first comprises determination of the loss of iodine demand when a portion of the sample is freed from suphides by acidifying and bubbling with an inert gas. In testing this method the procedure of Johnson (1) was followed, using nitrogen to remove the sulphide.

The second was to remove the sulphide with nitrogen to a zinc acetate receiving solution where it is titrated, as recommended by the Committee on Methods of Sewage Analysis of the Federation of Sewage Works Association (2). The procedure of the Committee was varied to the extent of using a train of flasks in place of the absorption tube.

For the purpose at hand it did not appear practical to attempt to add sulphides to sewage samples in such a way that the true sulphide concentration would be accurately known; sources of error are inevitable. Consequently use was made of samples of sewage and a partially treated sewage effluent which had been allowed to become septic. Judgment as to the accuracy of the methods is based upon internal consistency and a consideration of possible sources of error.

Results of determinations by both methods on 14 samples are included in Table II. They show that the first modification gave consistently higher results than the second, the difference being about 0.5

p.p.m. In seeking for an explanation of the discrepancy it was ascertained that when a bottle filled with sewage is acidified, stoppered, and allowed to stand, a loss of iodine demand occurs, although the sulphide concentration remains unchanged. This effect causes high results by the first modification, and is sufficient to account largely, if not entirely, for the discrepancy. In addition to this, irregular errors are certain to arise in this modification from the impossibility of securing sharp and stable end points in the presence of the suspended sewage solids; these errors are serious at low sulphide concentrations.

Three possible sources of error affecting both iodine methods suggest themselves. The first is interference from the possible presence of sulphites. Samples containing sulphites will lose sulphur dioxide when acidified and bubbled with inert gas. The sulphur dioxide will be retained by the zinc acetate solution; high results will be obtained by either method. Furthermore, in the acidified solution the SO_2 will react slowly with any H_2S which may be present, the principal product being thiosulphate if the medium is moderately acid. This reaction will cause high results in determinations by the first method and low results in the zinc acetate modification. A subsequent paragraph describes a modification to eliminate interference by sulphites. In the sewage samples used for the experiments, sulphites were proved to be absent.

A second source of error arises from interference of metallic salts which form insoluble sulphides. The metals of this class which are most likely to be present in small amounts in sewage are iron, zinc, manganese, tin, lead and copper. Sulphides of the first four metals are readily decomposed by acid and present no problem. Lead sulphide is decomposed slowly, but rapidly enough so that it causes errors only if a very large amount of lead is present or if insufficient acid is used. Copper sulphide is so insoluble that it does not show a test for sulphide by any of the methods investigated. This is of little importance, however, because copper sulphide can be ignored for most practical purposes.

The third source of error may arise from the volatilization of iodine-consuming substances other than H_2S. Sulphur dioxide has already been considered as one compound of this sort. Others of unknown identity may exist. Such substances will introduce errors into the zinc acetate modification only insofar as they are of a type to be retained by the zinc acetate solution. In seeking for an indication of such substances, sulphur determinations were made on the receiving solutions in three of the tests. The results were in good agreement with the iodine titrations. It may be concluded that the iodine demand caught by the zinc acetate solution did not include any appreciable amount of non-sulphurous material. Of the volatile sulphur compounds, only hydrogen sulphide, sulphur dioxide, and organic sulphides would be likely to occur in sewage, as far as is known. Sulphur dioxide was known to be absent, and organic sulphides are not held by the zinc acetate solution. Hence the iodine titrations apparently measured the true amount of H_2S evolved from the sewage.

Whether volatile iodine-consuming substances other than H_2S may escape from the sample and not be held by the zinc acetate, but nevertheless lead to errors by the first method, was not determined.

Incomplete absorption of the evolved H_2S by the zinc acetate would lead to low results. Completion of absorption can be determined by adding more absorption flasks and noting whether any sulphide is caught by them. Complete absorption was proved in this way in the experiments.

A consideration of the foregoing and other possible sources of error, in determinations made by the zinc acetate modifications, failed to reveal any factors which may have led to erroneous results (ignoring the possible presence of traces of CuS). In view of the fact that at least one serious error was involved in the determinations by the first modification, it appears that the discrepancies between the results by the two methods are due largely to inaccuracies of the first modification.

It may be concluded that for maximum accuracy in the sulphide determination, the zinc acetate modification, or some method equivalent to it in principle, should be used, and it is probable that the accuracy of the results is of a high order, except for interference by sulphites and by copper. It is doubtful if there are any cases in which the use of the first modification is justified.

When sulphites are present, interference may be largely eliminated by bubbling out the sulphide at a pH between 5 and 7. Addition of 0.5 gram of a primary phosphate (e.g. KH_2PO_4) to a 500-ml. sample of sewage of ordinary alkalinity will place the pH in a satisfactory range. Under these conditions no appreciable amount of SO_2 will be lost, and the reaction between SO_2 and H_2S will not likely be serious if the H_2S is removed quickly. Decomposition of the insoluble sulphides will be retarded, but the error from this source will not ordinarily be significant.

Antimony Method

The antimony method was first reduced to a form suitable for sewage analysis by Salle and Reinke (3), and was subjected to further study and modification by Johnson (1). Because of its simplicity, this method has been of great value in qualitative sewage analysis. Its accuracy from a quantitative view is seriously limited by the variable color, turbidity, and degree of dispersion of the antimony sulphide precipitate, and by the incomplete reaction of iron sulphide and other metallic sulphides. When the test is applied to sewage, less color is obtained for a given sulphide concentration than is obtained in pure solutions.

Samples of septic sewage were tested by the antimony method. At the same time the true sulphide concentrations were determined as well as possible by the iodine method. In the antimony method the procedure of Johnson was followed, except for these modifications: 2 ml. of a solution of 25 gm. of NaCl in 100 ml. of solution were used in place of 0.5 gm. of dry salt; the test reagent was made with 5 gm. of gelatine per liter instead of 10 gm. (to avoid coagulation); 2 ml. of the reagent were used instead of 1 ml.; and solutions of potassium chloroplatinate were used for measuring the colors. Chloroplatinate solutions were chosen for standards because of observations that the original standards of Salle and Reinke, containing $K_2Cr_2O_7$, $CoCl_2$, and HCl, fade quite rapidly if exposed to strong sunlight, and that the pure $K_2Cr_2O_7$ standards of Johnson also fade, although more slowly. For the purposes of this laboratory it was desirable to have standards of the permanence which can be attained with potassium chloroplatinate; the tests provided data for calibrating such standards. The chloroplatinate color is intermediate in hue between the Salle-Reinke and the Johnson standards, and matches very well the average color of the antimony sulphide precipitate. The stock solution chosen for making the standards is the same as that used in making standards for colorimetric determinations of iron (4). It contains 4 gm. of K_2PtCl_6 and 200 ml. of conc. HCl per liter of solution.

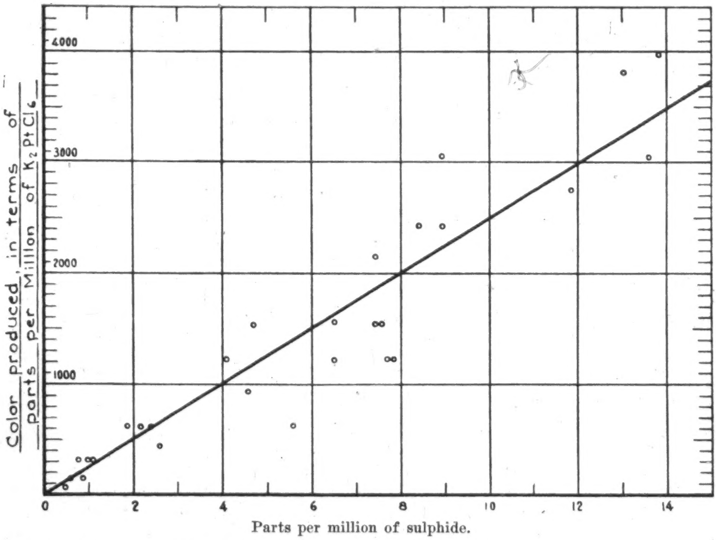


FIG. 1.—Color produced by Salle-Reinke test applied to sewage, as read by potassium chloroplatinate standards.

Results are shown in Figure 1. The scattering of the points indicates the erratic nature of the results. Better consistency would doubtless be attained if the method were applied to pure sulphide solutions, or even to sewage of low iron content, for the sewage at this plant usually contains 5 to 10 p.p.m. iron from industrial wastes, and even the effluent carries 3 to 5 p.p.m.

The average line of the figure shows that a solution of 250 p.p.m. K_2PtCl_6, or 6.25 ml. of the stock solution, diluted to 100 ml., provides a standard equivalent to 1 p.p.m. of sulphide in the sewage used for the tests. When standards made on this basis are compared with either the Salle-Reinke or the Johnson standards, it is found that the chloroplatinate standards show less than half as much color for a given sulphide concentration. This means that if sewage at this plant were tested with the Salle-Reinke or Johnson standards, the results would average less than half of the true values.

Communication with Mr. Reinke has brought out the fact that his original standards were calibrated with pure solutions. In applying the method to sewage he has found it necessary to revise the standards in the direction of less color. He states also that he tried chloroplatinate standards and found them very satisfactory, but he recommended dichromate because of its availability.

The average deviation of the points of Figure 1 from the mean line is 23 per cent. This variation, and the wide discrepancy of standards calibrated under different conditions, testify to the limited accuracy of the method. Conclusions as to its probable field of usefulness are presented in a subsequent section.

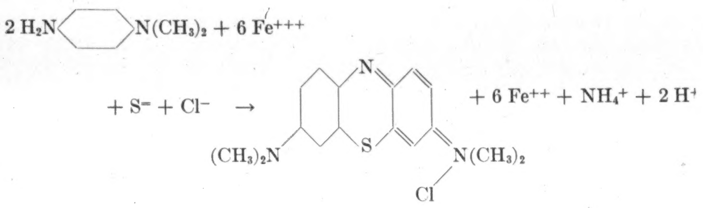
Other Methods Depending Upon Sulphide Precipitates

Some of the difficulties encountered in application of the antimony method to sewage analysis may be expected to inhere in any method which depends upon the formation of a precipitate of a metallic sulphide. Of the metals used in place of antimony, lead is most common. A lead acetate solution provides a simple qualitative test which will give a positive result in sewage containing more than 2 p.p.m. sulphides, but the results are of limited value from a quantitative point of view.

Tests were made with a commercial set using a lead solution. A sample of sewage containing 1.2 p.p.m. of sulphides read less than 0.6 p.p.m. by the lead method. A sample with 1.7 p.p.m. sulphides read 0.6 p.p.m. and 3.5 p.p.m. read 1.2 p.p.m.

Methylene Blue Method

In 1883 Emil Fischer (5) suggested that the reaction by which methylene blue is formed, referred to by various investigators as Lauth's or Caro's reaction, could be used as a qualitative test for sulphides. The reaction is unique in its extreme sensitivity, allowing the detection of 0.01 p.p.m. of sulphide. Almy (6) and others quoted by him recommended the method. The procedure as given by Almy is as follows: to 90 ml. of sample add 5 ml. of a solution of 0.4 gm. of para-amino-dimethyl-aniline in 1 liter of 6 N HCl, followed by 1 ml. of a solution of 3.2 gm. of $FeCl_3$ in 1 liter of 1.2 N HCl. The blue color which develops is read at the end of two hours by comparing with colors developed from solutions of known sulphide content. The reaction is:



The most thorough work on the test has been done by Lorant (7), who substituted sulphuric acid and ferric ammonium sulphate for hydrochloric acid and ferric chloride. The yellow color of ferric chloride was thereby greatly reduced, although it was necessary to add a small amount of NaCl to provide the chloride ion required in the reaction. Lorant was able to use more iron than was possible when $FeCl_3$ was used and thus to accelerate the reaction. He states that the color development is practically complete in 10 minutes, but recommends making the readings at the end of an hour.

Elder and Buswell (8) used the method of Almy, and gave directions for applying the test directly to sewage as a qualitative method. They also stated that "further work is being done on the development of this test for field use," but no further information has come to our attention.

Experiments conducted in this laboratory have shown that the methylene blue test can be modified in such a way as to provide a very satisfactory procedure for sewage analysis. For the purpose at hand the following facts must be taken into account:

1. Para-amino-dimethyl-aniline is rapidly oxidized by the air. Its salts are oxidized slowly, but in strongly acid solution it may be kept for long periods without serious change.
2. If $FeCl_3$ and para-amino-dimethyl-aniline are mixed in neutral or slightly acid solution a deep red color is produced. This color may be prevented from forming, or may be destroyed after it is formed, by addition of strong acids or of phosphates. The action of the phosphate is due to the formation of un-ionized ferric phosphate.
3. If the red solution is allowed to stand for a few minutes, the color slowly changes to purple. The purple color cannot be destroyed by acids or phosphates.
4. If $FeCl_3$ is added slowly to a very dilute solution of the amine, the red color at first increases with increasing concentration of $FeCl_3$, but when an excess of $FeCl_3$ is added the color largely disappears.
5. The reaction forming methylene blue requires an acid solution, but it may be inhibited by too strong acid.
6. The formation of methylene blue is inhibited by phosphates.
7. Addition of a strong acid to a methylene blue solution partially fades the color, but the color may be restored by neutralizing the acid. Furthermore, if methylene blue is formed in strongly acid solution and the acid is then neutralized, an intensification of the original color is observed.
8. The color of $FeCl_3$ in solution may be largely removed by addition of phosphoric acid or a phosphate.

The procedure for the test must be designed in such a way as to keep to a minimum the interfering colors, while at the same time quickly yielding the maximum blue color. These requirements are met by keeping the concentration of amine very low, using a large excess of $FeCl_3$, and most important, by adding di-ammonium phosphate after the blue color has developed. The addition of di-ammonium phosphate serves to eliminate the yellow color of $FeCl_3$ and the red color of the $FeCl_3$-amine combination, to prevent further formation of the purple color, to eliminate colors formed by certain interfering substances which might be present in sewage, and to neutralize enough of the acid to permit the methylene blue to show its maximum color. Sulphuric acid was found to be a better medium than HCl for making the test, even though the $FeCl_3$ color which caused Lorant to use sulphuric acid is eliminated by the phosphate.

Several hundred tests were made to determine the optimum concentrations of each reagent. The preparation of the solutions and the details of the basic procedure are as follows:

Solutions

1. Stock amine-hydrochloric-acid solution.

   The commercial para-amino-dimethyl-aniline (also called di-methyl-paraphenylene-diamine) is likely to be received as a mixture of crystals and liquid. Drain the crystals and press dry between filter papers. If the original material is entirely liquid, cool until it has partially solidified. If the dry crystals are quite dark in color, melt them in a closed vessel and again partially solidify by slow cooling. Seeding may be necessary to prevent too great supercooling. Again dry the crystals. Precautions should be taken to minimize oxidation, for the free amine, especially in the liquid state, reacts rapidly with the air. (Caution: If any of the amine gets on the hands, wash off with dilute hydrochloric acid. Contact with the skin at first causes a tingling sensation; later the affected part becomes numb for several days.)

   Add a known amount of the amine gradually to concentrated HCl in a beaker surrounded with ice. The final solution should contain 20 gm. of the amine in 100 ml. of solution. A pure solution would be colorless. Some discoloration is inevitable, but the solution should not be so dark as to be opaque.

2. Amine-sulphuric-acid solution.

   Dilute 500 ml. of concentrated sulphuric acid with enough water to make 980 ml. of solution. Cool and add 20 ml. of the amine-hydrochloric-acid solution.

3. Ferric Chloride Solution.

   Dissolve 45 gm. of $FeCl_3$ or 75 gm. of $FeCl_3 \cdot 6H_2O$ in enough water to make 100 ml. of solution. Provide a bottle with a dropper which will deliver 20 drops of this solution per ml.

4. Ammonium phosphate solution.

   Dissolve 400 grams of di-ammonium phosphate in 805 ml. of water; this makes 1 liter of solution.

Procedure

Pipette 7.4 ml. of the sample into a 5/8 in. test tube (clean but not dry). Add 0.5 ml. of the amine-sulphuric-acid solution, followed by 2 drops of $FeCl_3$ solution. Mix the contents. In the absence of sulphides a pink color at first appears, but soon fades. If sulphides are present the blue appears at once. After 1 minute add 2 ml. of the ammonium phosphate solution, 1 ml. at a time, mixing after each addition. A temporary precipitate of ferric phosphate forms, but re-dissolves. Also, a temporary pink color can again be observed in the absence of sulphides. After 1 minute the color may be read. The color will remain unchanged for 24 hours or more, except that if solids settle out some color will be carried down.

The foregoing basic procedure is applicable for sulphide concentrations up to 10 p.p.m. If the sulphides are above 10 p.p.m., two alternatives are offered. The first is to add more of the reagents. Prepare a diluted amine-hydrochloric-acid solution by adding 3 volumes of conc. HCl to 1 volume of the stock amine-hydrochloric-acid solution. Provide a dropper delivering 25 drops of this solution per ml. Assuming the sulphides to be between 10 and 40 p.p.m., add one drop of this solution to the test after adding the amine-sulphuric-acid solution, and follow this with 3 instead of 2 drops of the $FeCl_3$ solution. If the sulphides are above 40 p.p.m., 1 drop of amine-hydrochloric-acid solution and 1 drop of $FeCl_3$ may be added for each additional 30 p.p.m. of sulphide, but samples containing more than 100 p.p.m. should not be tested directly. In 5/8 in. test tubes the color is too intense for satisfactory comparison above 20 p.p.m., although with smaller test tubes readings may be made up to 40 p.p.m. At higher concentrations dilution must be resorted to before the color can be read.

The other alternative is to dilute the sample before developing the color. If a two-fold dilution is required, pipette 7.4 ml. of water into a test tube, add 1.0 ml. of the amine-sulphuric-acid solution, and pipette in 7.4 ml. of the sample, injecting it so that it mixes with the diluting water. Add 4 drops of $FeCl_3$, mix, and after 1 minute add 4 ml. of ammonium phosphate. If higher dilutions are necessary, an analogous procedure is followed, always adding the amine-sulphuric-acid solution to the diluting water before adding the sample to be tested.

This latter alternative is generally preferable, and is recommended in all cases for sulphide concentrations above 40 p.p.m. The former alternative is useful where sulphides are consistently high. It is permissible in these cases to increase the amount of amine in the amine-sulphuric-acid solution.

The amount of amine used in the basic procedure is equivalent to 26 p.p.m. of S. If the sulphide concentration is greater than 50 p.p.m. the color formation is retarded, and very high sulphide concentrations (above 200 p.p.m.) practically inhibit the reaction unless larger amounts of the amine and ferric chloride are used.

If a series of tests are being made, the tube used for the test must be rinsed each time with fresh water, otherwise the phosphate remaining from the previous test will combine with some of the $FeCl_3$.

Reasonable care should be taken to use the specified amounts of reagents. The relative amounts of acid and ammonium phosphate are balanced in such a way that the ferric phosphate will just remain in solution at the end of the test. Moderate variation of the acid concentration would not affect the test if the phosphate were varied proportionally. At an acid concentration half as great as specified a noticeable pink color will be observed when the sulphide concentrations are very low. If twice as much acid is used, the formation of the blue dye will be appreciably diminished. If the amount of phosphate used is too great for the amount of acid, a white precipitate will remain at the end of the test. If this condition should be observed, due to inaccuracy in following the procedure, the precipitate can be redissolved by adding another drop of the amine-sulphuric acid solution, or any other acid. If insufficient ammonium phosphate is used, the blue color will be slightly diminished due to the un-neutralized acid, but this diminution is scarcely appreciable if the amount of ammonium phosphate used is 3/4 of the specified amount.

If the concentration of amine is half as great as specified, and the other reagents are unchanged, no difference in the color will be noted at sulphide concentrations below 5 p.p.m. If the amine is twice as great, the faint purple color will be noticeable at low sulphide concentrations.

If other reagents are used in the amounts specified, the quantity of $FeCl_3$ used may be half as great or twice as great without affecting the color.

One minute is specified as the time to be allowed for color development. The reaction is nearly complete in one-fourth of a minute, and no noticeable further change takes place for several hours. After adding the phosphate some further color change occurs. Ordinarily at least one minute should be allowed before reading the color, although for approximate results the readings may be made almost at once. For maximum accuracy, especially in the presence of suspended solids, it is desirable to wait five minutes or even longer. The accuracy is not diminished if the color is not read for 24 hours.

Methods of Reading Colors.—Lorant (7) states that the reaction forms, in addition to methylene blue, a small amount of a dye which he calls "methyl red" (not, however, the indicator of that name). The color produced by the procedure outlined in this paper was found to match very well the color of pure methylene blue except at sulphide concentrations below 1 p.p.m. But even at these low concentrations the difference of color is not of practical importance.

Two methods are suggested for reading the colors. The first is by use of the customary type of block comparator and standards made of methylene blue solutions or other coloring agent. The other method is to prepare a second tube identical with the first tube except that no amine is used, and then to add methylene blue to this tube until the color of the first tube is matched. For the preparation of the second tube, 18 N H_2SO_4 (conc. H_2SO_4 diluted 1:1) is used in place of the amine-sulphuric-acid solution. For practical purposes the amount of dye added may be determined by counting the number of drops of a solution of known strength. This latter method, which will be referred to as the "drop method," has the advantage that the known amount of dye is dispersed in a solution practically identical with the unknown.

In making comparisons between the drop method and the block comparator method, the unexpected fact was discovered that when methylene blue is dissolved in the solution which results from the additions of the reagents as specified, it presents just 25 per cent more color than when it is dissolved in pure water. Hence the amount of methylene blue used to make up standards for a block comparator must be 25 per cent larger than the amount used for the drop method.

Standardization and Accuracy Tests in Pure Solution

The methylene blue method was standardized against solutions made from National Aniline and Chemical Co. U.S.P. methylene blue, containing, according to label, 88 per cent of dye. A sulphide solution was prepared by washing a clear crystal of $Na_2S.9H_2O$ and adding it to a full bottle of water previously acidified with HCl. Subsequent dilution gave suitable sulphide concentrations. These solutions were tested by the methylene blue procedure. Iodine titrations, with suitable end-point corrections, were used to give the true sulphide concentrations in each dilution of the solution. The colorimetric analyses in those solutions containing more than 10 p.p.m. of sulphide were made by using more amine and $FeCl_3$ rather than by diluting prior to the reaction. In some of the tests, the colors were matched against pure methylene blue solutions; in others the dye was added to comparative tubes after the manner of the "drop method." In those cases where the comparisons were made with methylene blue in pure water solution, the apparent methylene blue concentration was divided by 1.25 to compensate for the difference in media. No significant difference was noted between the two groups of results.

The results of 28 tests on solutions having from 0.05 p.p.m. to 40 p.p.m. of sulphides are shown in Fig. 2. The average deviation of the points from the median line is 6.8 per cent. The tests of Lorant show an average error of 2.0 per cent. The superior accuracy attained by Lorant can be attributed to the use of a good colorimeter and to other refinements of technique, whereas the data of Fig. 2 were obtained with the use of ordinary test tubes and without any attempt to secure accuracy greater than is practical in the application of the test to routine sewage analysis.

Six tests were made with solutions containing from 40 to 100 p.p.m. of sulphides. The color per part of sulphide averaged 6% more than at the lower concentrations.

The median line of Fig. 2 indicates that when a sample containing 1.00 p.p.m. of sulphide is tested, the color is matched by a corresponding tube in which the actual concentration of methylene blue is 4.72 p.p.m. (assuming that the methylene blue used for standards was 88% dye). When 7.4 ml. of sample is tested, the final volume, including 0.3 ml. of water which is present on the sides of the wet test tube before the test, is 10.3 ml. Hence 1 milligram of sulphide produces 6.57 milligrams of methylene blue. According to the equation, 1 mg. of sulphide should give 9.97 mg. of the dye. The "yield" is 66 per cent. Of the remaining 34 per cent, some doubtless escapes as gas, but most of it is lost in side reactions. Lorant obtained a yield of 68.8 per cent.

When the drop method is used, the volume of solution in the comparative tube is increased by the addition of the drops. A correction may be made for this effect, or the concentration of the methylene blue may be adjusted to compensate for the effect in an average case.

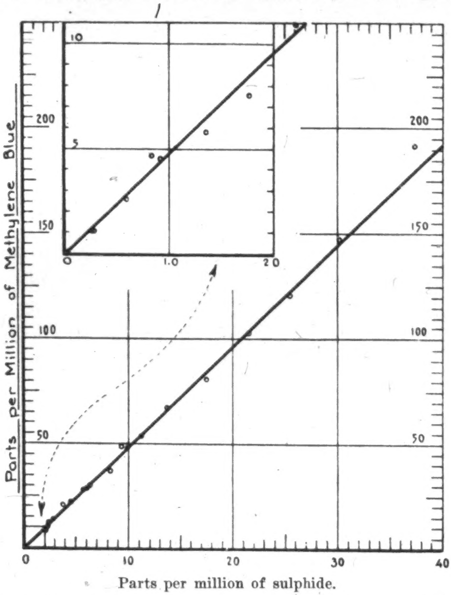


FIG. 2.—Methylene blue produced from sulphides in pure solutions.

For example, suppose that a dropper is available which will deliver 25 drops per ml. of methylene blue solution, and assume that on the average 6 drops will be used. The final volume, including the water with which the test tube will initially be wet, will be 10.54 ml. To match a sulphide sample of 1 p.p.m., the comparative tube must contain $10.54/1000 \times 4.72 = 0.0497$ mg. of dye. Assuming that the available supply of methylene blue is 88 per cent pure, a solution should be made containing $0.0497 \times 25/0.88 = 1.410$ mg. per ml., in order that 1 drop may correspond to 1 p.p.m. of sulphide. A solution of one-tenth this strength may be made for fractional parts.

When a block comparator is used, the samples in the compensating tubes must be treated with acid, except in cases where the acid has no effect upon the color of the sample. For maximum accuracy the compensating tubes may be treated in a manner identical to the reaction tube, except that 18 N H_2SO_4 is used instead of the amine-sulphuric acid solution. In ordinary cases it is satisfactory to add 0.5 ml. of 18 N H_2SO_4 to 7.4 ml. of sample and dilute to 10 ml.

Standards for the block comparator may be made from solutions containing 5.90 p.p.m. of 100 per cent methylene blue for each p.p.m. of sulphide. However, the methylene blue solutions are not permanent. Standards for the lower concentrations fade appreciably in 2 or 3 days, although standards above 5 p.p.m. may be used for 1 or 2 weeks. For permanent standards inorganic salts must be used. Approximate color matches may be secured with copper sulphate or copper nitrate solutions. Better matches are secured with mixtures of vanadyl sulphate and cobalt sulphate. Directions are as follows:

Vanadyl sulphate solution: Secure a supply of pure powdered vanadium pentoxide, V_2O_5, or prepare same by heating ammonium vanadate at a temperature just below a red heat. Add 30 grams of V_2O_5 to a flask containing a mixture of 18 ml. of c.p. conc. H_2SO_4 and 100 ml. of water. Saturate the mixture with sulphur dioxide gas, keeping a current of the gas bubbling through the solution for at least an hour. Stopper the flask and allow to stand over night. On the next day if the solution does not smell strongly of SO_2, or if any considerable amount of V_2O_5 remains undissolved, saturate again with SO_2 and allow to stand for a longer period, preferably in a warm place. When the reduction of the V_2O_5 is complete, add 50 ml. of water, filter the solution, and boil to expel excess SO_2. Dilute a portion of the solution to one-tenth its former concentration. Pipette 5 ml. of this diluted solution into a flask containing about 100 ml. of water, add 5 ml. of conc. H_2SO_4, and titrate with N/10 $KMnO_4$ until a faint pink color indicates an excess of permanganate. One ml. of N/10 $KMnO_4$ is equivalent to 5.096 mg. of V. Dilute the original solution or concentrate by boiling until it contains 8.29 grams of V per 100 ml. of solution.

TABLE I.—*Preparation of Permanent Standards for Use in 5/8 In. Test Tubes*

Add the following volumes of solutions to enough water to make 10.0 ml:

P.p.m. of Sulphide	Ml of $VOSO_4$ Solution	Ml of $CoSO_4$ Solution
Below 3	0.5 per p.p.m. of sulphide	0.00
3.0	1.50	0.00
4.0	1.97	0.12
5.0	2.41	0.31
6.0	2.83	0.56
7.0	3.21	0.84
8.0	3.58	1.14
9.0	3.92	1.46
10.0	4.24	1.79
11.0	4.56	2.13
12.0	4.80	2.51
13.0	5.03	2.87
14.0	5.21	3.23
15.0	5.34	3.54
16.0	5.38	3.80
17.0	5.39	4.02
18.0	5.39	4.23
19.0	5.40	4.41
20.0	5.40	4.59

Cobalt sulphate solution: Dissolve 14 grams of $CoSO_4$ or 25.4 grams of $CoSO_4.7H_2O$ in water, add a few drops of H_2SO_4, and dilute to 200 ml.

Mix the solutions according to Table I in order to prepare standards suitable for use in 5/8 in. test tubes.

Application to Sewage Analysis

The application of the methylene blue method of sulphide determination to sewage analysis involves first a consideration of the effect of adsorption of the dye by the suspended matter. That some of the dye is adsorbed by the suspended matter can be shown by settling or filtering a sample of sewage containing methylene blue.

The effect of this adsorption can be evaluated by setting up in a block comparator pairs of tubes containing fresh sewage and clear water. A definite amount of methylene blue is added to one sewage tube and one water tube. The comparison will indicate whether the adsorption diminishes the color intensity.

When tests of this kind were made with normal sewage at Los Angeles County plant, containing about 400 p.p.m. of suspended solids, of which 75 to 80 per cent were organic, no diminution of color was observed as a result of adsorption. But after a heavy storm, when the sewage contained a considerable amount of clay due to run-off water, the color was reduced to less than half intensity and was changed to a more purplish hue. Settling of the samples showed that the dye was practically completely adsorbed by the clay. It is evident that if samples containing clay are analysed and the colors read by comparison with permanent standards, the results will be low. But if the drop method is used, the adsorption of dye in the comparative tube will be the same as the adsorption in the test and the error should be largely eliminated. It is necessary in these cases to allow at least five or ten minutes for the dye to come to equilibrium with the clay.

The methylene blue method was tested in sewage from which the coarser solids had been settled, so that about 300 p.p.m. of suspended solids remained, and also in a partially treated sewage effluent with about 100 p.p.m. A few tests were also made with sewage containing clay, and with sewage clarified by aluminum sulphate. In all cases the colors were matched against comparative tubes according to the "drop method," except that the methylene blue solution was measured with a pipette. The samples were also analysed by the zinc acetate modification of the iodine method, and in part of the cases additional analyses were made according to the directions of Johnson (1). Results are shown in Table II.

Since the zinc acetate modification is the most reliable method available to measure sulphides in sewage, the results obtained by that method represent our best knowledge of the true sulphide concentrations of the samples. In those samples containing less than 3.0 p.p.m. of sulphides, the agreement of the methylene blue method with the zinc acetate modifications, while not so close as in simple solutions, is never-

TABLE II.—*Comparison of Methylene Blue Method with Iodine Methods as Applied to Sewage.*

Type of Sample	Sulphides, as Determined by Methylene Blue Method	Sulphides, as Determined by Zinc Acetate Modification of Iodine Method	Sulphides, as Determined by Loss of Iodine Demand Upon Acidifying and Bubbling with N_2
Sewage	0.29	0.24	0.63
"	0.44	0.40	0.96
"	0.54	0.60	0.92
"	1.23	1.11	1.71
"	3.6	4.19	
"	4.8	5.35	6.87
"	5.6	6.89	
"	6.1	6.48	7.20
"	8.0	10.30	
"	13.2	16.50	
"	17.8	19.80	
Sewage containing clay	0.63	0.56	0.93
" " "	2.21	2.33	
" " "	5.25	5.62	5.77
Effluent	0.15	0.18	0.31
"	0.18	0.196	
"	0.41	0.39	0.60
"	1.49	1.59	1.56
"	1.61	1.60	1.67
"	4.9	5.83	6.40
"	5.0	5.86	6.32
Clarified Sewage	1.36	1.40	
" "	3.1	2.98	
" "	14.6	14.11	
Miscellaneous*	0.225		0.38
"	0.53		0.90
"	0.90		1.38
"	2.00		2.62
"	3.68		4.33

* Each set of data in this group represents the average of results on 4 to 6 different samples

theless satisfactory. The average error of eleven results with sewage and effluent in this low-concentration range is 10 per cent, with no tendency for the results to be consistently either high or low. But in the case of the ten samples of sewage and effluent containing more than 3.0 p.p.m. the results are low by amounts varying from 6 to 22 per cent, averaging 14 per cent. The reason for this error is not known.

The entire group of 21 results with sewage and effluent average 6 per cent low. The average plus and minus error is 12 per cent. In an analytical set designed for testing sewage, the consistent error may be taken into account by using 6 per cent less color in the standards. The irregular errors will then average 9 per cent.

When the methylene blue method is applied to clarified sewage, the accuracy apparently is as good as in pure solutions.

Interfering Substances

As has been mentioned, clay reduces the color intensity by adsorption of the dye. This leads to low values if the color is compared with permanent standards, but the error is eliminated by use of the drop method.

The manner in which very high concentrations of sulphide interfere with the test has also been mentioned. Other strong reducing agents likewise prevent the formation of the color. Sulphites up to 10 p.p.m. as SO_2 have no effect. Higher concentrations retard the reaction and lead to low results, but if the concentration of $FeCl_3$ is increased to 6 drops and the time for the reaction is extended to 5 minutes, accurate results may be obtained in the presence of 40 p.p.m. of SO_2.

Thiosulphate, due to its ability to reduce methylene blue to the colorless state, prevents any color formation until it is oxidized. No serious intereference arises at thiosulphate concentrations below 10 p.p.m. By increasing the $FeCl_3$ and extending the time, the test may be used accurately in the presence of 40 p.p.m. of $S_2O_3^=$.

Hyposulphite, $S_2O_4^=$, is decomposed by acid. H_2S is found among the decomposition products; accordingly hyposulphite gives a sulphide test by any of the methods which require addition of acid to the sample.

Potassium thiocyanate was added to a sample of sewage to the amount of 50 p.p.m. In making the sulphide test, a red color at first developed, but disappeared after the addition of the ammonium phosphate. The final blue arising from the sulphides which were present in the sewage was the same as in a sample to which the thiocyanate was not added. Similar results were found in the presence of 50 p.p.m. of butyl mercaptan.

Colloidal sulphur has no effect on the test.

Suspensions of iron, zinc and lead sulphides apparently react just as readily as dissolved sulphides. Copper, however, binds the sulphide so tightly that no test can be obtained; this is true for any method of determining sulphides in sewage.

Chlorine produces a purple color, but this is not noticeable at chlorine concentrations below 10 p.p.m. The chlorine color could not be mistaken for the blue produced by sulphides, and since sulphides will not be found in the presence of chlorine, no interference can arise from this source.

Nitrites give a pale yellow color, which can be detected at nitrite concentrations as low as 0.5 p.p.m. When solutions containing nitrite and sulphide are acidified, a reaction occurs which oxidizes the sulphide to sulphur. The reaction is not sufficiently rapid, however, to prevent some blue color from appearing, even when 5 p.p.m. of NO_2^- is present with less than 1 p.p.m. of sulphide. A sample of sewage containing 1.0 p.p.m. of nitrite and 0.5 p.p.m. of sulphide gave a color corresponding to 0.4 p.p.m. of sulphide. Nitrites and sulphides are not likely to be found together except for short distances below confluences of streams carrying the constituents separately. Hence the fact that nitrites cause low readings in the sulphide test is of little practical importance

Other Applications

An attempt was made to apply the methylene blue method directly to determination of small amounts of H_2S in gas. Preliminary results appear promising, but no satisfactory procedure has yet been devised.

The methylene blue method affords a convenient procedure for approximate determinations of sulphides in sludges. It is necessary in this case to first dissolve the sulphides in acid. For example, determine the volume of a bottle holding around 100 ml. Add enough of the amine-sulphuric-acid solution to equal 6.75 per cent of the volume of the bottle. Fill just to the neck with water. Pipette in 2 ml. of the sludge, injecting it well below the surface. Completely fill the bottle with water, stopper and shake. After 2 or 3 minutes, pipette 7.9 ml. into a test tube, add 2 drops of $FeCl_3$, and finish as in the ordinary sulphide test. The reading must be multiplied by 0.47 times the volume of the bottle to give the parts per million of sulphide in the sludge.

Relative Merits of the Antimony and Methylene Blue Methods

The outstanding advantages of the methylene blue method in comparison with the Salle-Reinke method are its superior accuracy and sensitivity. Standards for the antimony method calibrated for pure solutions give readings more than 50 per cent low when applied to sewage of the type used in this research. Readings with standards calibrated for this sewage show erratic errors averaging 23 per cent. In contrast to this, the methylene blue method applied to sewage gives results with an average error of 12 per cent, tending to be low by 6 per cent, if use is made of standards calibrated for pure solutions. With standards calibrated for sewage the irregular errors averaged 9 per cent.

The antimony method will not with certainty detect sulphides in sewage if the concentration is less than 1.0 p.p.m. The methylene blue method readily shows 0.1 p.p.m., and by using larger volumes sulphide concentrations as low as 0.01 p.p.m., can be measured. Even though the accuracy of the methylene blue method is sometimes not required in sewage analysis, it is secured with practically no extra trouble.

Another advantage of the methylene blue method is that the distinctive hue and greater color intensity reduce the uncertainty arising in the analysis of turbid and colored samples. Furthermore, the small size of the required sample allows the use of a more compact set, and also makes the method of particular advantage where the amount of material to be analyzed is limited. If necessary, sulphide concentrations down to 0.1 p.p.m. can be measured with less than 1 ml. of sample.

The antimony method suffers serious interference by iron salts, which are commonly present in sewage in small amounts. The methylene blue method is not seriously affected, as far as is known, by any compounds ordinarily present in sewage. However, it cannot be used without modification for testing certain oil refinery wastes containing sulphites and thiosulphates, nor for paper mill wastes.

One disadvantage of the methylene blue method is the difficulty of preparing the reagents. This is not serious, however, because enough stock amine-hydrochloric-acid solution can be made in one batch to last for a long time. One hundred ml. of this stock solution is enough, assuming no loss, to make 10,000 tests.

Where only qualitative results are desired, and where one wants a cheap, simple, quick and practically fool-proof method, the antimony method will still be of use. One may obtain a qualitative result with the use of a very indefinite quantity of tartar emetic solution, without the use of any other reagents. But to obtain results of even roughly quantitative significance, as much care and time must be used as is required for the methylene blue method.

Forms of Sulphides in Sewage

For the ordinary purposes of sewage analysis, it is sufficient to distinguish three sulphide forms: total sulphides, dissolved sulphides and hydrogen sulphide.

Total sulphides provide a measure of the septicity of the sewage, and also indicate, in part, the chlorine requirements for chlorination. If the sewage is to be treated by an aeration process, the total sulphides represent a chemical oxygen demand, increasing the oxygen requirements of the process.

The procedures discussed in the foregoing sections provide means for determining the total sulphide content of sewage.

Knowledge of the concentration of sulphides in solution is of importance because it measures the amount of sulphide which ultimately can escape as gas, and because of the bearing which it has on the determination of the concentration of free hydrogen sulphide. Of the total sulphides in sewage, a part will be present in the suspended solids in the form of the insoluble sulphides of iron and other metals. In purely domestic sewage, only a few tenths of a part per million of sulphide will be held in the solids; any excess over this amount will be in solution. If iron salts have been added to the sewage, much larger amounts of sulphide may be held in the solids.

In order to separate the insoluble from the dissolved sulphides, a procedure must be used which does not allow escape of hydrogen sulphide from solution, nor absorption of oxygen from the air. Filtration is impractical. The most satisfactory method is to settle the solids with the aid of a flocculating chemical such as aluminum sulphate. The equilibrium between suspended and dissolved sulphides may change as a result of changes of pH, hence the pH should be held constant in the flocculating step. The following procedure has been found to give satisfactory results with the sewage used for these tests:

Solutions are prepared containing, respectively, 24 gm. of $Al_2(SO_4)_3.18H_2O$ per 100 ml. of solution and 9 gm. of NaOH per 100 ml. of solution. A 125-ml. oil sample bottle is filled just to the neck with the sample. Two-tenths of a ml. each of the aluminum sulphate and the sodium hydroxide solutions are added. The bottle is completely filled, stoppered without air bubbles, shaken, and allowed to stand. After ten minutes clear liquor may be pipetted off; this liquor may then be analyzed for its sulphide content by any suitable method.

For many purposes it is desirable to know the concentration of free hydrogen sulphide in the sewage, as this quantity controls the *rate* at which H_2S gas can escape to the atmosphere. An understanding of ionic equilibria is essential at this point.

If H_2S is dissolved in water, an ionization equilibrium is established, represented by the equation:

$$H_2S \longleftrightarrow H^+ + HS^-.$$

A second stage of ionization may occur, leading to the formation of sulphide ion, but no significant amount of sulphide ion is formed below a pH of 12, and hence this second ionization is of no importance in sewage.

The ratio between hydrogen sulphide and hydrosulphide ion (HS^-) is determined by the hydrogen-ion concentration according to the equation:

$$\frac{(H^+) \times (HS^-)}{(H_2S)} = 9.1 \times 10^{-8}.$$

From this expression one may calculate the fraction of dissolved sulphides in the form of H_2S at any pH value. Results of calculations at certain pH values are shown in Table III. The fraction is the same regardless of whether hydrogen sulphide or any other soluble sulphide is used to make the solution.*

TABLE III

pH	Percent of Dissolved Sulphides in the Form of: H_2S, %	HS^-, %
5.0	99	1
6.0	92	8
6.6	73	27
7.0	52	48
7.4	31	69
8.0	10	90
9.0	1	99

Thus, the directions for determining free hydrogen sulphide in sewage are: (1) determine the pH of the sample, (2) determine the dissolved sulphides, and (3) from the data of Table III calculate the H_2S.

Only free H_2S can escape from solution. Hence the figures of Table III indicate the relative rates at which dissolved sulphides can escape. For example at pH 7.0 the H_2S can escape from solution only about half as fast as from an acid solution of the same concentration of total dissolved sulphides, while at pH 9.0 the amount escaping will be negligible under most conditions. Experimental verification of these conclusions has been presented elsewhere. (9) These results are of practical significance, for there are conditions under which H_2S nuisances can be abated by raising the pH, as for instance by the use of lime. Furthermore, use of Table III in conjunction with data on solubility of H_2S at various temperatures provides a means of calculating the concentration of H_2S in a gas phase in equilibrium with a given solution.

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* Sodium sulphide, calcium sulphide, etc. do not exist as such in sewage. If a few parts per million of sodium sulphide are dissolved in pure water, ionization and hydrolysis will occur, and the resulting solution will contain Na^+, OH^-, HS^-, and H_2S.

Table III does not indicate the total amount of H_2S which may escape, because as fast as H_2S is removed, the equilibrium is re-established by combination of H^+ and HS^- to form more H_2S. Thus all of the sulphur in any dissolved inorganic sulphide may be ultimately removed as H_2S.

Some investigators have attempted to distinguish "volatile" from "non-volatile" sulphides by removing the volatile portion by bubbling with carbon dioxide, nitrogen or air. All dissolved sulphides will be gassed out if the pH is low, which will be the case if CO_2 is used. But if nitrogen or other inert gas is used, the simultaneous loss of CO_2 will, under usual conditions, allow the pH to rise to the point where further loss of H_2S will be slow and probably incomplete. If air is used, a part of the sulphides will be oxidized. In any case, the result reported as "volatile sulphides," as found by these methods, is doomed to be an indefinite and useless quantity.

SUMMARY

1. Two modifications of the iodine method for determining total sulphides in sewage were compared. The modification in which a determination is made of the loss of iodine demand when a portion of the sample is acidified and bubbled with inert gas proved to be subject to such serious errors that its use is not indicated for any purpose. The method depending upon volatilizing the sulphide to a zinc acetate receiving solution, where it is titrated, apparently is quite accurate under ordinary conditions.

2. The antimony method gives low and erratic results when applied to sewage. It is subject to serious interference by iron salts.

3. It has been found that the methylene blue reaction furnishes a very satisfactory colorimetric method for determining sulphides in sewage, provided certain modifications are made in the procedures recommended by previous investigators. The most important modification consists in the addition of di-ammonium phosphate after the development of the color. The modified procedure accomplishes practically complete color development in less than one minute; an entire test requires only two or three minutes. In sewage of high sulphide content the color development is somewhat deficient in comparison with pure solutions, but on the whole the accuracy is sufficient for most purposes. A standardized procedure allows determinations over a range of sulphide concentrations from 0.1 p.p.m. to 10 p.p.m. and by slight modification the range can be extended from 0.01 p.p.m. to 100

p.p.m. This method is preferable to the antimony method for most purposes.

4. Dissolved sulphides may be determined by removing the suspended matter with the aid of aluminum sulphate. Hydrogen sulphide may be calculated from the pH and dissolved sulphide concentration. Attempts to separate "volatile" and "non-volatile" sulphides by direct analytical procedures are futile.

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Plant Operation

INCINERATION OF STACK GASES AT THE PASADENA SLUDGE DRYING PLANT *

By A. W. Wyman

Supt., Sewage Treatment Works, Pasadena, Cal.

After many years of experimenting at Pasadena with various chemicals, oxidizing agents and apparatus to eliminate odors from the dryer exhaust gases released to the atmosphere from the sludge drying process, we feel that we have finally found a method that actually does deodorize the gases. These gas odors, like many others, can be destroyed by high temperature oxidation, and we have followed this procedure for several years with varying success. Due to heat loss in the previous types of furnaces for deodorization, and inability to attain the high temperature necessary for complete odor control, the fuel cost was almost prohibitive. For the fiscal year 1933–34 fuel for drying cost $7,360 and for incomplete deodorization $7,200; for the fiscal year 1934–35 the cost was $7,404 for drying and $6,654 for deodorization.

About two years ago experiments were being made at the University of California, at Berkeley, at the suggestion of Dr. F. G. Cottrell, on a type of heat-exchanger which had been developed by Mr. P. H. Royster. This experiment was carried on under the supervision of Charles Gilman Hyde, Professor of Sanitary Engineering. The results of that experiment, and one carried on by us later at our plant, with the same apparatus, convinced us that with a unit of sufficient size we could accomplish the result for which we have long strived: complete deodorization of the dryer exhaust gases.

The necessity for removing the dust particles from the exhaust gases before they entered the Royster-Cottrell Deodorizer was considered. It was decided that even though the danger of the dust particles clogging the deodorizer was problematical, it would be better to remove the dust and thus avoid any possible difficulty from this source. An attempt was made to remove the dust particles from the exhaust gases by a dry method, hoping to retain the heat in the gases as they entered the deodorizer (200 to 240 deg. F.). The dry method was unsuccessful, the moisture content of the gases being too high for this type of dust collection. Two steel spray towers, 5 ft. 6 in. in diameter and 17 ft. high, were constructed and installed. The spray towers were equipped with 27 spray nozzles delivering approximately 160 g.p.m. of plant effluent at 40 lb. pressure. These towers have been very satisfactory from the start and to all appearances are accomplishing at least 90 per cent removal of the dust. A reduction in temperature from

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240 deg. F. to 100 deg. F. by washing appeared to be a serious heat loss when it is considered that 15,000 cu. ft. per min. of exhaust gases have to be raised to a temperature of 1200 deg. F. in passing through the deodorizer. It has been suggested, and I think correctly, that in reducing the temperature of the saturated exhaust gases from 240 to 100 deg. F. considerable water is condensed and dropped out in the spray towers, thus reducing the load on the deodorizer and compensating for any heat loss, or in other words, accomplishing a fair exchange.

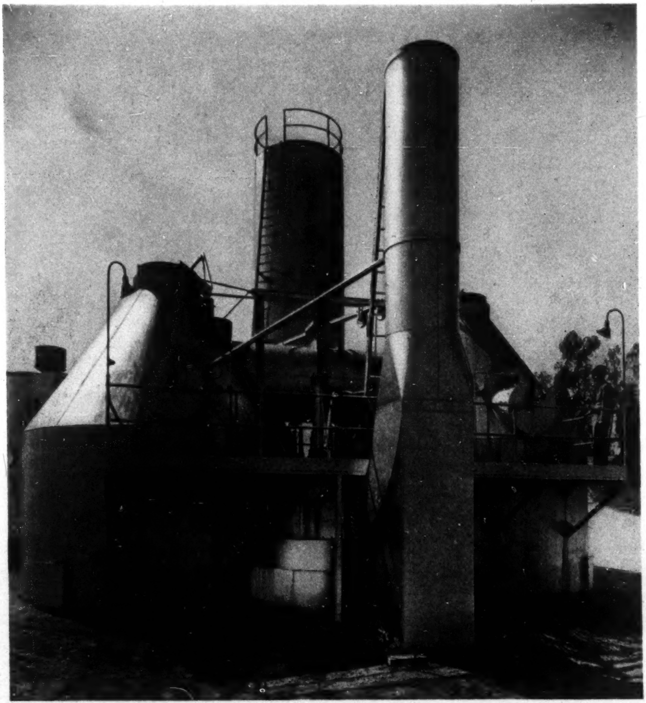

Fig. 1.

The deodorizer (Figs. 1 and 2) consists of two cylindrical shells, with cone shaped tops, 17 ft. in diameter and 20 ft. high, lined with 4½ in. insulating brick and 4½ in. of refractory brick, joined together by a 5 ft. insulated passage near the top. Hydraulic reversing valves direct the flow of gas through the deodorizer and thence to the stack which discharges to the atmosphere. On the top of each cylinder is a 3 ft. insulated water-sealed cover, which is used to normalize the deodorizer. Frequency of normalizing is determined by the change-over intervals. Each cylinder contains 10 ft. of rock, about 90 tons, graded in size from 6 to 1½ inches. This rock bed extends from the floor up to the base of the cone. The cones serve as combustion chambers, with fuel supplied by four 1-in. open-pipe gas burners, and four ⅛th in. pilots. Auxiliary air was also provided but was found unnecessary, as the gases will support combustion at the temperature maintained in the hot zone. A recording thermometer is used to obtain the temperature of the gases leaving the spray towers and passing through the stack to the atmosphere after deodorization. Twelve thermo-couples in six parallel zones of each cylinder are connected to an indicating pyrometer, assuring very accurate control.

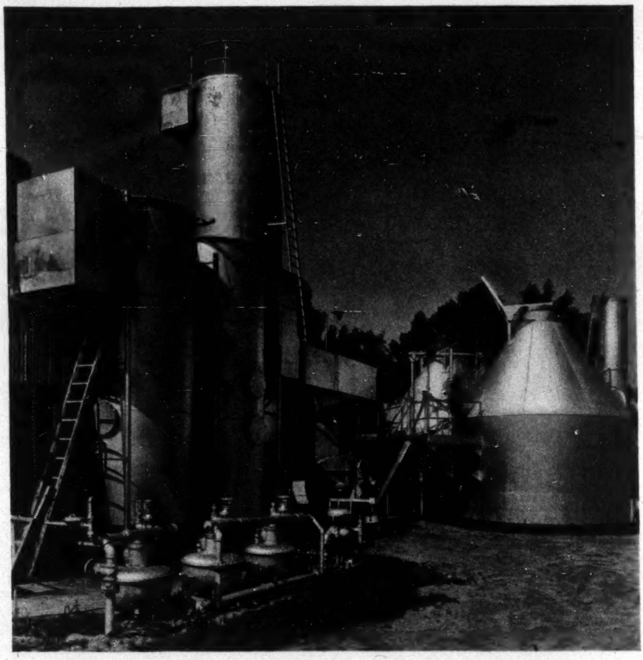

FIG. 2.

The operation of the deodorizer is quite simple. The burners are lighted and the combustion chambers and top of rock beds heated to about 1200 deg. F. An exhaust fan having a capacity of 15,000 cu. ft. per min., and located in the duct between the spray towers and the deodorizer, forces the washed gases upward through No. 1 stove, over to No. 2 stove, passing downward through the rock bed and out to the stack. As previously stated, the temperature of the washed gases is about 100 deg. F.; in passing through the hot zone of the deodorizer the temperature is raised to 1200 deg. F. In the downward passage through the second stove, heat is taken up by the rock bed, reducing the temperature of the gases to 150 deg. F., at which temperature they are discharged to the atmosphere. As this continues, the temperature in the rock bed of the second stove gradually increases until the gases are discharged at 200 deg. F., at which point an automatic signal is operated by a mercury switch in the pyrometer, ringing a gong to attract the attention of the operator in charge. After reading and recording the necessary thermal points the valves are reversed and the gases pass upward through the No. 2 stove and downward through No. 1 stove. The change-over cycle varies slighly but is approximately at 40-minute intervals. A point is reached when both rock beds have reached nearly the same temperature in parallel zones, the heat having progressed to the lower rock zone so that the reversing cycles are considerably shortened. The deodorizer then has to be normalized. This is done by raising the cap of the stove in which the gases are passing upward, allowing them to pass directly to the atmosphere, thus forcing the heat to a higher level in the rock bed but cooling the lower zones. This requires about 15 minutes and is necessary only about every 48 hours. Deodorization is not affected during the normalizing period as the temperature, while discharging to the atmosphere, is in excess of that required to deodorize. Many combinations were tried to determine the most economical discharge temperature and change-over cycle but none showed any advantage over the arrangement originally decided upon, which was to keep the discharge temperature from the deodorizer the same as the temperature of the exhaust gases leaving the dryer.

In designing the deodorizer it was expected that it would be necessary to use two of the 1-in. gas burners at all times to maintain the desired temperature in the stoves. In actual operation it was found that after the desired temperature in the hot zones had been reached it was necessary to use only the ⅛-in. pilots with 1½ lb. gas pressure to maintain 1150 to 1200 deg. F. in the hot zone. This was a very pleasant surprise, as you can well realize. During the 24-hour period each week that the dryer and filters are not operating, the valves on the deodorizer are closed, resulting in a temperature drop of only 300 deg. F. through radiation.

Never in our experience has a new piece of equipment been started up and continued in operation with so little difficulty. Much credit is due Mr. O. H. Hedrich, Mechanical Engineer of the Pasadena Municipal Light Department, who designed and supervised the construction of the deodorizer. The apparatus was placed in operation November 4, 1935, and has been in continuous operation since. The common shut downs for changes, adjustments, etc., were very conspicuous by their absence.

Elimination of the odors from the dryer exhaust gases has been the most troublesome problem at the plant and after the many attempts made, it is very gratifying to have found a means of accomplishing deodorization that is both successful and economical. After hearing a few cost figures and comparisons I believe you will agree that we have every reason to be well pleased with the Royster-Cottrell Deodorizer.

Comparison of Gas Consumption and Cost for Deodorization

	Incinerating Stack 12/1/34—3/31/35	Royster-Cottrell Deodorizer 12/1/35—3/31/36	Saving
Cu. Ft. Gas Consumed	14,590,100	2,473,800	12,116,300 cu. ft.
Cost *	$2,431.68	$412.30	$2,019.38
Tons Fertilizer Produced	1,081.6	1,139.25	
Average cost per ton	$2.24	$.36	$1.88

* For the purpose of comparison the present price per thousand cubic feet of gas was used for both 4-month periods.

The above figures indicate a saving of $6,000 per year. There is, however, some increase in power cost using the Royster-Cottrell deodorizer due to the necessity of using another fan to force the gases through the rock beds. This increase, comparing the same periods taken for gas consumption and cost, is $403.42, leaving a net saving of approximately $4,800 per year.

The cost of the Royster-Cottrell Deodorizer installation, including much experimental expense, was less than $20,000. It has been estimated that the unit as finally designed and installed could be duplicated for approximately $16,500, which indicates that the initial cost will be offset by savings in about four years.

DISCUSSION

E. A. REINKE: I would like to check up on one point. Under the old system you received many odor complaints but are you getting any now?

MR. WYMAN: We have one chronic kicker who made the only complaint we have received just after this paper was written. It is not serious.

MR. HYDE: There is one word I want to say about the Pasadena situation. Very seldom do we find a community with the guts—and I use that word advisedly—to undertake something which has never been done in the world before. Dr. Cottrell had the imagination to see that that type of stove could be used for the destruction of odors. Mr. Wyman had the courage and foresight to enable him to adapt the process to the destruction of odors from the sludge dryer at his plant. It is one of the finest things I have heard of in the whole field of sewage treatment. I am proud to be able to say that it came from California. One reason we can not operate garbage reduction plants is because of the frightful odors the process produces. This Mr. Wyman has solved.

EXPERIENCES AT NEWPORT BEACH, CALIFORNIA *

I. INFILTRATION INTO SEWERS

By R. L. Patterson

City Engineer

Infiltration of groundwaters into sanitary sewers is a most important matter. The expense of increased capacity of outfall sewers, pumping stations, treatment plants and operation costs is increased in direct proportion to the amount of infiltration.

The City of Newport Beach, California, situated on Newport Bay, has a land area of 1,570 acres. Approximately 980 acres has an elevation varying from 7 ft. to 12 ft. above mean lower low water. The lower area comprises a sandy peninsula with a width of 1,000 to 1,500 ft. and two islands which are reclaimed swamp lands. The ground water level averages about 3 ft. above mean lower low. The maximum depth of sewers is 4 ft. below mean lower low water or 7 ft. below the water table. The topography is such that flat grades are necessary in order to reduce pumping costs as well as the expense of installation in wet ground.

The existing sewer system is divided into two separate systems. District No. 1 provides for the peninsula and Lido Isle and District No. 2 provides for Balboa Island. There are four pumping stations in District No. 1 and two in District No. 2. The pumping lifts vary from 10 to 25 feet.

District No. 1 has 16.4 miles of sewer mains and laterals, which includes 11 miles of cement concrete pipe, from 8 to 20 in. in diameter, and 5.4 miles of vitrified clay pipe from 8 to 15 in. in diameter. Thirty-nine percent, or 34,000 lineal feet of the pipe is below the ground water table. The present estimated infiltration in this district is 300 gallons per minute. Infiltration was determined by the chloride content and sewage flow over a 24-hour period. Samples taken at 2-hour intervals showed from 9,200 to 10,500 p.p.m. chloride, whereas sea water contains about 19,000 p.p.m. chloride.

The City specifications allow for a maximum leakage of 0.6 gal. per min. per inch of internal diameter per 1,000 ft. of wet trench. This is equivalent, for 8-in. pipe, to 36,500 gal. per mile per day. Any individual leaks that are visible on final inspection are repaired, though the total amount of infiltration may be within the specification limits.

The allowable quantity of infiltration under the specifications in District No. 1 is 50,000 gal. per mile per day, compared with the estimated present infiltration of 67,300 gal. per mile per day.

District No. 2 has 5.3 miles of cement concrete pipe, from 8 to 12 in. in diameter. Approximately 81.5 per cent, or 22,800 lineal feet of the pipe line is below the ground water table. The estimated infiltration in this district is 85 gal. per minute. The allowable quantity of infiltration under the specifications is 38,000 gal. per mile per day, compared with estimated present infiltration of 28,200 gal. per mile per day.

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* Presented before the Eighth Spring Conference of the California Sewage Works Association, Ontario, Apr. 24, 1936.

The large amount of infiltration in the sewer system is a result of poor construction or inspection, and the earthquake of March 10th, 1933, particularly in District No. 1 where the first sewers were constructed along the peninsula in 1921. The sewers were installed on Lido Isle in 1930 and in District No. 2 in 1926. The earthquake damage to sewers, water mains and other structures along the peninsula was much greater than on Lido Isle or Balboa Island. Accurate information is not available as to the quantity of infiltration in District No. 1 prior to the earthquake. However, the pumping records indicate an infiltration of 140 gal. per minute, or 31,400 gal. per mile per day, which is 46 per cent of the present infiltration.

The earthquake of 1933 caused considerable damage to the sewer system. The flow in both districts following the quake was more than doubled. An inspection of the pipe lines showed in District No. 1 a number of breaks at the pipe joints and in the pipe itself adjacent to several manholes, and small leaks at the joints. The larger leaks were repaired at considerable expense. The reconstruction of certain sections could be made at less cost than attempting to repair the small leaks at the joints. Lack of funds has prevented the reconstruction of the worst sections. Since repairs were made to the major leaks the infiltration has decreased materially, due to the small cracks at joints partially sealing up of their own accord.

The salt water infiltration, amounting to 50 per cent of the total flow, enters the small Imhoff tank at Plant No. 1. In addition to the infiltration, three small fish canneries discharge as high as 300 gal. per minute of sea water into the sewer. The canneries are operated spasmodically. When the canneries are operating at full capacity, the total flow consists of 600 gal. per min. of salt water and only 300 gal. per min. of sewage. The Imhoff tank is operated at three times its capacity. This excessive amount of salt water has not interfered noticeably with the sludge digestion, but the amount of solids removed from the sewage has been seriously affected. Steps are being taken to eliminate about 70 per cent of the salt water from the canneries by returning a portion of it to the bay.

Plans are now being prepared for a new treatment plant to replace Plant No. 1, and 10,000 feet of new 27 in. sewer main. The plans provide for the reconstruction of 600 lineal feet of the old sewer line above Plant No. 1, including a syphon across the old Santa Ana River Channel. The reconstruction of this section will eliminate about 80 gal. per min. of infiltration. Deterioration of the old concrete pipe will eventually force the reconstruction of a considerable portion of the main in District No. 1.

On sewer construction, great care should be exercised to obtain stable foundations and tight lines. You many prepare rigid specifications, but after all a good job is secured only by having a capable inspector on construction. An experienced inspector should remain upon the work at all times when pipe is being laid or manholes constructed, regardless of the confidence you may have in the contractor.

The pipe lengths should not be less than three feet and the joints made of mortar composed of one part cement and one part sand. Metal gaskets and forms used in pouring joints on sewers of small diameter in water-bearing ground produced excellent joints. I have preferred cement joints to the so-called tar or mastic joints, but we are now considering specifying mastic joints on the new 27-inch line, principally because of the flexibility to withstand an earthquake. In a wet trench where marsh land or quicksand is encountered, the pipe line should be encased in concrete, either to the spring line of the pipe or completely around the pipe.

The material generally encountered at Newport Beach is fairly coarse sand, which means plenty of water, but we have found that a good foundation was secured by excavating 6 or 12 inches below grade and filling in with 3/4 in. rock. Care should be exercised in backfilling and the removal of sheeting. Frequent tests must also be made as the work progresses by allowing the ground water to rise up over the completed work to see if tight work is being done.

Sewer construction is being done more carefully today than in the past. Ordinary rates of infiltration in a well constructed sewer vary from 3,000 to 40,000 gal. per mile per day. Most authorities upon the subject fix a rate not to exceed 20,000 gallons. However, I feel that this rate can be materially reduced by proper inspection.

Our present concern has to do with the effect of this high concentration of chloride on the production of H_2S and biological purification processes which might be contemplated for Newport Beach.

II. HYDROGEN SULPHIDE CONTROL

By Scott-Darcey Process

Newport Beach has had a problem to control odors at Imhoff Tank No. 1. This tank is greatly overloaded and poorly located along the State highway. Pre-chlorination of the sewage at the plant was started by the city in 1928.

A chlorinator with the Scott-Darcey Process was recently installed on the main 3000 ft. above the Imhoff tank, so as to supply ferrous chloride to the sewage. The maximum winter sewage flow is 900,000 gal. per day. Ferrous chloride is being added to the sewage at a uniform rate, regardless of the variation of sewage flow. At the present time 42 lb. chlorine with 1500 gal. water per 24 hours is being added to a large reaction chamber from which pure ferrous chloride is being discharged into the sewage main. This results in a dosage of from 10 to 12 p.p.m. of ferrous chloride.

The chlorine solution is discharged into a reaction tank. This tank consists of two chambers into which mashed cans from the scrap heap are dumped. The chlorine solution is brought in through a rubber nipple iron pipe inlet cast into a 6 in. wall of the tank and leading to the bottom of the first reaction chamber. Each of the reaction chambers has a liquid depth of 4 ft. and a liquid surface area 4½ by 5 ft. There is a solid division wall between the two chambers except for the insertion of a 4 in. iron soil pipe with an inlet at the surface level of the liquid in the first chamber and an outlet at the bottom of the second reaction chamber. The ferrous chloride is carried from the liquid surface of the second reaction chamber to the point of application through a 4 in. soil pipe cast in the concrete.

An expandable rubber plug is inserted in the bottom of each chamber to facilitate drainage. It will be noted that if the cans are assumed to occupy 10 per cent of the volume of the reaction tanks, that each chamber has a capacity of 742 gallons and that when 40 pounds of water are used per pound of chlorine and the total chlorine consumption is 42 pounds per day, there is a 21 hr. contact between chlorine and iron.

As a result of the use of the Scott-Darcey Process, the hydrogen sulphide odor at the plant has been less noticeable. Waste from the fish canneries discharged into the sewers has created considerable odor at the plant. The fish odor practically kills the hydrogen sulphide odor. Before the installation of the Scott-Darcey Process, tests showed about 5 to 8 p.p.m. hydrogen sulphide at the Imhoff tank. Recent tests at the plant showed from 1 to 2 p.p.m. hydrogen sulphide.

OBSERVATIONS ON THE OPERATION OF SEWAGE TREATMENT PLANTS *

By C. C. Agar

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The last few years have brought notable advances in the design and construction of sewage treatment plants. Increased mechanization of units, improved sludge digestion facilities, revival and refinement of chemical treatment, and development of practical methods for rapid dewatering and incineration of sludge have each contributed to the trend in treatment practice.

There has been also a general acceleration of the processes of treatment. The older types of plants were usually characterized by long detention periods and a lapse of many months between the sedimentation of the raw sewage solids and the final removal of the solid from the drying bed as sludge cake. Detention periods have been reduced and the digestion process has been speeded up by providing heated separate sludge tanks. The drying time was shortened by placing the sludge beds under glass, and more recently sludge filters have demonstrated their value in rapidly dewatering sewage solids. Incinerators have also been developed to burn sewage sludge cake satisfactorily. We can even now envision the day when consulting engineers will be promising "from sewage to ashes in an hour."

Progress in the installation of treatment plants has also been accelerated. There can be no doubt of the active stimulation of such projects by the provision of state and federal relief funds for such works. During 1935 fifteen municipal sewage treatment plants were completed or placed in operation in New York State, representing an expenditure of about $2,600,000. Since 1925 the number of municipal plants in the state has more than doubled, there now being over 200 such installations.

In addition to the projects recently completed there are also many either under construction or definitely financed. At the beginning of the year (1936) there were some 27 such P.W.A. projects under way for sewerage, involving an estimated total cost of over $53,000,000. Sewerage projects for which funds have been allotted by the W.P.A. numbered 652 with an estimated cost of nearly $39,000,000. This work includes such large projects as the completion of the Wards Island activated sludge plant at New York City, intercepting sewers and treatment works for the city of Buffalo, the Ley Creek interceptor at Syracuse, and interceptors and treatment for the cities of Auburn, Niagara Falls, and Elmira. It is estimated that when the present active projects are completed, the population served by sewage treatment facilities will be more than double the present population served.

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* Presented at the Spring Meeting of the New England Sewage Works Association, Hartford, Connecticut, April 27, 1936.

Definite trends in sewage treatment practice are indicated by analysis of some of the recent projects. Of the 15 plants completed last year, only 2 provided for the Imhoff type of settling tank, the remainder making use of mechanical sludge removal equipment in plain settling tanks. Among some 21 active treatment projects at the present time, we find that all of the large plants and the majority of the small plants will be provided with mechanically equipped settling tanks. Four of the large installations, namely, the Coney Island plant in New York and the plants at Auburn, Elmira and Freeport, will employ chemical treatment and vacuum filters for dewatering the sludge. Incinerators will be provided for final sludge disposal at the Auburn and Elmira plants. Digestor gas will be utilized for generation of the power required at the Coney Island plant for pumping and operation of mechanical units.

There has been a noticeable improvement in the general operation and control of treatment plants during the past few years. Much of this improvement can be attributed to closer supervision and the activities of organizations such as this in stimulating not only the interest of the plant operator, but also that of the municipal official and the general public as well, in the important role that sewage treatment plays in the control of man's environment.

But with all the advances being made in sewage treatment the plant operator still has to contend with many of the same old problems and in addition new ones incidental to the new treatment devices. Mechanical equipment requires regular attention, adjustment and repairs when necessary. The operator of the modern plant must have not only a knowledge of sewage treatment but must also understand motors, machinery, boilers, gas engines, etc. He becomes more responsible as treatment plants become more complex. As long as we have sewage treatment plants there will always be the need for the plant operator and there will always be problems for him to solve.

One of the most common problems is that due to excessive sewage flows from storm water or during periods when infiltration may be high. Such a condition is not confined to combined sewer systems handling both surface and sanitary sewage, but may also be found in old sanitary systems and unfortunately in some of the newer systems. There are instances where the sewage flow may be so high that sewer lines are surcharged, causing sewage to back into cellars and overflow manholes and to create many nuisance conditions. Settling tanks and filters may be overloaded so that it is necessary to bypass the plant or a large part of the flow. While elimination of these excessive flows may appear to be an insurmountable undertaking, a survey of the system will frequently disclose a few major sources of ground or surface water entrance and in such instances repairs or reconstruction of portions of the system are warranted. At Glen Cove, a few years ago, an investigation showed the connection of a spring flowing 300,000 g.p.d. to the sanitary system and diversion to the storm water system reduced the sewage flow to that extent.

Roof leader connections are sometimes a cause of periodic high flows and their elimination can usually be carried out without great difficulty by enforcement of local regulations. Cellar drain connections on the other hand, although discouraged, have come to be considered almost a part of a sanitary system, particularly where storm sewers are not available.

During the construction boom days in towns near the city of Buffalo a great many miles of sanitary sewers were constructed in proposed real estate developments. The expected boom did not materialize and there are now many miles of sewers through undeveloped areas in some of these towns. Infiltration rates are high, due in part to improper construction, and sewage reaching the treatment plants is dilute. However, careful surveys of some of the systems showed that there were many roof leader connections and numerous lines where field drains had been connected. Elimination of many of these connections brought about a marked reduction in the sewage flow.

There may be, of course, some systems where the cost of locating and eliminating points of entrance of storm water must be carefully weighed against the additional cost of pumping and treatment. It is sometimes more economical to enlarge the treatment facilities to take care of peak sewage flows than to make extensive repairs or changes in the system.

There is another difficulty frequently encountered during the spring of the year in sewer systems where infiltration may be high. Slime growths or so-called ''zoogleal masses,'' developed in the sewer lines during the cold weather, break away and greatly increase the quantity of screenings, sometimes clogging a bar screen within a few hours. More frequent raking is required but as such trouble is usually of comparatively short duration no special control of such growths in the sewer system has been considered practical.

Operating difficulties may also result from having too little sewage flow. This may be true during the first few months after a new system is installed, when there are few house connections. In sewer lines laid on minimum grades there is sometimes lack of self-cleansing velocities and resulting deposition of solids may produce a septic and foul-smelling sewage reaching the treatment plant. There may also be an insufficient sewage flow to maintain a trickling filter in operation during the winter. For example, a new plant consisting of an Imhoff tank and a trickling filter was constructed at Spencerport a few years ago. Because of the small flow from a limited connected population, the sewage in the Imhoff tanks froze over in the winter and it was necessary to bypass the trickling filter in order to prevent freezing of the risers and distributors in the bed. Performance tests of the new plant at Great Neck, which provides vacuum filtration of a settled sewage using paper pulp as a filter medium, have been delayed, pending a sufficient sewage flow to operate the plant continuously. At the present time a total of five hours' operation each day is sufficient to treat the flow.

Odors at a treatment plant are objectionable and when such odors reach homes or highways in the vicinity of the plant they must be corrected. Fortunately, there are very few odor problems which cannot be controlled by the use of chemicals or by some change in operation. One of the most serious odor problems encountered has been in the operation of an Imhoff tank-trickling filter installation at Lyons, New York. Sewage enters a pump well at the plant through two trunk lines and is pumped intermittently to the Imhoff tanks. The sulphate content of the water supply is unusually high and during the summer season hydrogen sulphide odors from the plant have been objectionable for distances as great as one-half mile from the plant. The Imhoff tank provided an average detention period of over eight hours and under such conditions the sewage became extremely septic and odors were liberated in great quantity when the trickling filter nozzles were operating. Experimental work carried out during 1934 demonstrated that prechlorination would be effective in controlling odors. The cost, however, was considered high so that a modified type of treatment was suggested for use during the 1935 summer season. This treatment consisted in the use of a solution of iron chloride made by passing chlorine solution through a tower of scrap iron. This proved effective in controlling plant odors and a permanent installation is planned.

A similar odor problem has been encountered at East Aurora, where the plant is located within a few hundred feet of a built-up portion of the village. The trickling filter was responsible for an odor and fly nuisance. A chlorine-iron tower has been installed and placed in operation at this plant, with encouraging results.

Chlorine in some form is still the most effective chemical agent for control of odors and there have been a large number of chlorinator installations made for this purpose. In all cases these installations have proved effective and such treatment is now considered as almost essential for the modern treatment plant.

Odor nuisances may come not only from the sewage itself but also from poorly digested sludge. This was the experience at the Huntington, Long Island, plant where an unheated separate digestion tank was provided. It was practically impossible to control digestion in this tank and the sludge gave off obnoxious odors even though confined to a glass-covered sludge bed. It was found, however, that this odor could be controlled by liberal doses of chloride of lime intimately mixed with the sludge as drawn. When poorly digested sludge must be drawn it is now standard practice to treat such material with chloride of lime before applying to the drying bed. This plant has since been provided with a heated separate sludge digestion tank and no further odor problems have been encountered.

In most installations, however, the digestion of sludge can be controlled. This applies not only to separate digestion tanks but also to Imhoff tanks, where the judicious use of hydrated lime for control of the pH value of the sludge will prevent serious nuisances from acid digestion.

The control of digestion includes the control of scum or floating solids in a digestion tank. Excessive scum in the gas vents of an Imhoff tank is frequently found at some plants, particularly at institutions where such condition seems to be correlated with the presence of grease from kitchens and large volumes of laundry wastes.

At most of the new state institution plants, provision is made to remove the scum from the gas vents to separate digestion tanks designed for this particular purpose. Under most conditions scum in the gas vents of an Imhoff tank can be controlled by frequent agitation, supplemented at times by the use of hydrated lime.

Excessive scum or an "upside down" tank is also found occasionally where separate sludge digestors are used. This is particularly true where the tanks are unheated. It may also occur in heated tanks particularly during the first year or so of operation. Such a condition in a heated tank is usually of relatively short duration and agitation and pH control soon bring satisfactory results.

In some instances, however, recirculation and stirring have not been effective. At Ithaca, where the sludge is digested in a separate tank with mechanical mixing, the scum required frequent removal to prevent overloads on the stirring mechanism. There was no particular characteristic of the raw sewage or condition in the plant which could explain this difficulty. Plans were made for experimental use of activated carbon last fall at the plant but in the meantime a mechanically raked bar screen was substituted for the hand raked installation. The quantity of screenings removed increased two to three-fold to about 10 cu. ft. per m.g. and to date no further scum problem has occurred. It is too early yet to attribute the solution of this problem to the mechanical screen but the results are certainly indicative.

At the Rome plant, where sludge is digested in a tank equipped with a floating cover it was recently found that a 7-foot accumulation of scum was interfering with heating and digestion. It could not be settled by agitation or recirculation. Analysis of the material indicated an ether extractable content of about 40 per cent and the presence of a large amount of mineral oils which will require removal from the tank. This depth of scum has been a gradual accumulation over a period of about five years and during the past winter became serious. It was learned that oil frequently reached the plant requiring removal from the settling tanks by skimming. Enforcement of regulations regarding oil separators and their maintenance is believed to be a logical means of preventing a recurrence.

Foaming difficulties in tanks during the past few years have been practically unknown and it is believed that this is due to the regular determination of the pH value of the sludge and prompt steps to add lime if necessary. Another factor of importance in improving the operation of tanks is the retention of "seed" sludge in the digestion compartment, rather than to empty the tank, as was a common practice.

Some difficulty in the operation of sand filters has been caused by overloading or industrial wastes. The Hobart plant was receiving all of the wastes from a large local milk by-products plant. The presence of large amounts of milk solids in the wastes soon resulted in clogged beds. The industry took steps to install equipment for the recovery of the milk solids and the wastes from the plant consisting only of clear water were discharged directly to the stream. This change soon resulted in improvement and recovery of the village treatment plant after the sand beds were cleaned.

The clogging and ponding of trickling filters has been practically unknown during the past few years. More careful operation of the primary settling tanks has been a factor and manual work on the bed itself has minimized clogging difficulties. The occasional use of chlorine or chloride of lime applied in the dosing tank at high rates of 50 to 100 p.p.m. has also reduced manual work and clogging in many instances. At the Fairport plant chloride of lime is spread over the filters each year in the spring at a rate of about 2000 pounds per acre. These treatments are effective in freeing the beds from accumulated surface growths.

Odor problems from trickling filters may be serious local nuisances but it has been found that more careful operation of the primary tanks and pretreatment with chlorine or chlorinated iron will control such difficulties satisfactorily.

There are very few plants in the state where flies from the trickling filter might become a nuisance outside the plant site as most installations are located at a considerable distance from dwellings. At the Schenectady plant flies are controlled by periodic flooding of the trickling filter units.

There have been two instances indicating the necessity of taking special precautions to protect gas lines from sludge digestion tanks. At a small plant serving Iola Sanatorium in Rochester the waste gas line extended from the flame trap vertically through the roof of the building. It was found that gas was escaping into the building from the flame trap, creating not only an explosion hazard but a serious health hazard as well. Investigation of the gas line showed that where exposed above the roof during the winter it had completly clogged with frost. This condition was corrected by providing insulation for the line.

At the Rome plant a similar frost problem and clogging of the flexible hose line from the gas dome to the control house was experienced. Here the installation of a 1/4 in. steam line inside the gas line prevented further difficulty.

Industrial wastes entering a sewer system may produce a variety of operating problems. Milk wastes predominate as a cause of such problems, particularly where such wastes contain large amounts of milk solids such as skim milk or whey. In such instances elimination of all wastes, excepting possibly wash water and can rinsings, from the sewer system has been advocated. A conventional type of plant can handle a limited volume of wash water but is seriously affected if the amount of milk solids discharged is high. Odors, acid digestion, clogged filters, high chlorine demand and foul conditions in the outlet watercourse have resulted where mixed milk wastes were admitted to the sewer system. When the new plant, consisting of an Imhoff tank and chlorinating equipment, was placed in operation at Cooperstown a few years ago, it was found that whey from a cheese plant made it impossible to maintain residual chlorine in the plant effluent with the chlorinator provided, and produced acid and septic conditions in the Imhoff tank. The cheese plant was closed and the sewage plant has operated since without difficulty.

Milk wastes consisting of wash water and whey also affected the operation of the new Malone plant, producing serious acid conditions in the digestors. Plans have been made to remove all of the whey from the milk plant to a by-products plant in another village where the milk solids will be salvaged. On the whole we find that the milk industry is appreciative of the difficulty of disposing of milk wastes and are generally willing to cooperate in solving local problems.

Cannery wastes are another source of difficulty at the treatment plant. Shortly after the new Geneva plant was placed in operation last year a large quantity of beet tops reached the plant daily, overloading the mechanical bar screen and clogging the sewage and sludge pumps. The cannery will install a mechanical screen for removal of all such material before the 1936 canning season. At the Rome plant, where the sludge is digested in a tank equipped with a floating cover, it was found that a large portion of the scum in the tank was composed of pumpkin seeds. Here again a fine screen has been recommended for pretreatment of the canning wastes by the industry.

In instances where Imhoff tanks are used the tank may be completely upset so that even a fair quality of plant effluent cannot be obtained. Acid sludge, excessive scum formation, and obnoxious odors have resulted. Preliminary treatment of the wastes by fine screening and more careful operation and control of the Imhoff tank have been able to correct this difficulty in most localities.

Acid wastes entering a sewer system are particularly detrimental to treatment processes. About a year ago it was noted that the activated sludge plant at Mineola had been upset so that no activated sludge could be maintained in the system. This change in the condition of the plant occurred during the daytime when the operator was present. The incoming sewage had a peculiar yellow color and a sample was collected, but at the time the nature of the waste was not known. All industrial plants in the village were investigated and finally a small chromium and nickleplating plant was visited. An analysis of the sewage sample collected showed the presence of large amounts of chromium salt and it was subsequently admitted that an electroyltic vat had been discharged into the sanitary sewer system. The presence of acid wastes and cyanides had undoubtedly caused this upset in the activated sludge process.

Another experience involving acid wastes was in connection with an Imhoff tank trickling filter installation near Buffalo. Here it was apparent that iron pickling wastes had been discharged into the sanitary sewer system. The sewage was rendered acid and it was impossible with the equipment provided to maintain a residual chlorine content in the effluent due to the high demand of the ferrous sulphate in the sewage. The stones on the trickling filter became coated with a brown deposit of iron and it was necessary to add large amounts of lime to the Imhoff tank to correct the acid condition of the sludge.

The effective chlorination of sewage and sewage effluents frequently presents unusual problems. There are few automatic chlorinators in use in New York State and even such chlorinators cannot compensate for variations in chlorine demand due to changes in the strength of the sewage. Proportioning of the chlorine dosage in accordance with the flow is, however, an advantage.

Most chlorinators are of the manual control type and must be regulated frequently or adjusted so as to provide adequate chlorine for peak rates and concentrations of sewage. Therefore, when unusual changes occur the chlorine dose may be inadequate and can only be corrected by frequent manual adjustment of the machine.

An interesting solution of a problem at Corning, New York, is cited. The chlorinator at the plant was installed to provide for addition of chlorine to the sewage entering the pump well, from which it is pumped intermittently to Imhoff tanks. Because of variable sewage flows and a liberal detention period in the Imhoff tank, it was frequently impossible to maintain a satisfactory residual in the tank effluent. The point of application of part of the chlorine solution was changed to the plant effluent line, but the extreme variation in flow due to the intermittent operation of the pumps still made it impossible to disinfect the effluent effectively at all times. It was therefore decided to attempt to equalize the flow from the tanks and a weir was installed in the effluent channel and provided with submerged ports. The effect of this weir was to utilize the sedimentation compartment of the tank as an equalizing chamber and provide a more uniform flow of the plant effluent. This installation proved satisfactory and effective chlorine residuals are being maintained in the plant effluent.

There are many other operating problems that might be included in a discussion of this type but it is believed that the foregoing will indicate the diversity and nature of recent experience. In New York State we are able to keep in close touch with the operation of most plants through frequent inspection and the receipt of monthly operating reports from some 140 treatment plants.

Great progress is being made generally in sewage treatment, and the operation and control of sewage treatment plants in New York State shows continued improvement, reflecting the greater interest taken in the plants by the operator and the officials in charge. Operating problems are being encountered, but with a better understanding of such problems, improved cooperation of those concerned and the collective experience with similar difficulties, such problems are being solved satisfactorily.

EXPERIENCES WITH DIGESTER FOAMING *

By Harry E. Schlenz

Vice President, Pacific Flush-Tank Company

One can appreciate the wide scope of successful operation of sewage treatment plants, when consideration is given to some of the problems that are encountered, regardless of whether the treatment process involves digestion in Imhoff tanks or in separate chambers. Successful methods in one locality may be failures in others.

The outstanding feature of Imhoff and separate digestion tanks is their temperamental nature, especially during the first months of operation. It appears that, either properly or improperly, we classify most of our digestion troubles under the heading of "foaming"—therefore a discussion of the subject must necessarily cover a fairly wide field.

The New York State Department of Health in their manual on the "Operation and Control of Sewage Treatment Plants" (19) give the following definition:

"Foaming" is a term used to describe the condition which develops in Imhoff or separate digestion tanks where froth, gas and scum rise in the gas vents or scum compartment and may be carried over into the sedimentation compartment or flow out of the tank."

Some of the possible causes of "foaming" which have been advanced, and which will be discussed individually, are as follows:

1. Excessive loadings of raw solids in relation to digesting solids in the tank.
2. Increased activity causing rapid formation of gas and "boiling" action.
3. Objectionable organisms in the sewage and in solids settled from the sewage.
4. Character of the sewage such as the predominance of objectionable products such as laundry, cannery, brewery wastes, etc.
5. Departures of the pH from normal.
6. Marked viscosity of the liquid or scum, and also the mechanical action of gas attempting to escape through scum having a high surface tension.
7. Character of the raw solids loading.
8. Restricted area of gas vents.

It is evident that some of the above causes may overlap or be definitely related, or that the "Experiences of Plant Operators" which will be related may even come under causes different than the writer has selected.

1. *Excessive Loadings of Raw Solids in Relation to Digesting Solids*

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* Presented at the Eighth Spring Conference of the California Sewage Works Association, Ontario, California, April 25, 1936.

in the Tank.—Rudolfs has suggested in a Report of the New Jersey Experiment Station, 1926 (see Outline, page 620), that the digestion of sewage solids may be divided into three stages or periods, for consideration of the differences in the nature of digestion. It will be noted that if there is too great a volume of solids undergoing the first two periods of digestion, as would happen with an excessive raw solids loading, that there will be a tendency for acid conditions to prevail.

Downes (4) indicates that the production of organic acids in the first stages of digestion will cause an inhibiting effect, bringing digestion to a halt.

It appears that we encounter most of our "foaming" troubles when a tank is first started. This is generally the case with modern heated separate digestion tanks, indicating that digestion is retarded either because of the producing of this inhibiting condition or the lack of a condition which will promote digestion.

It is the writer's contention that only actively digesting material may be counted upon in balancing the acid-producing tendencies of raw solids and thus aid in promoting digestion.

Hatfield (23) relates an experience at Decatur, Illinois, where as Plant Superintendent he had shut down his Imhoff tanks for three months to install gas vent covers. A liberal amount of digested sludge with a volatile solids content of 25 to 30 per cent was retained in the tanks for seeding purposes. However, when raw solids were added the tanks foamed just as though they were being started for the first time.

Since digested sludge occupies valuable space it should be removed frequently to allow capacity for actively digesting material—in fact the strictest routine should be followed in withdrawing sludge so that the proper balance may be maintained. Too great a withdrawal at any one time will upset the balance.

Correspondence with C. C. Larson, Operator and Chemist at Springfield, Illinois, indicates that on August 1, 1935, they were operating two out of their six tanks as primary units receiving raw solids, and within three months they began to have violent "foaming" troubles. The pH was not too low, but the assumption was that these tanks were being loaded too heavily with raw solids, so on January 1, 1936, another tank was cut in as a primary, making three tanks for the receiving of raw solids. This apparently eliminated the "foaming."

2. *Increased Activity Causing Rapid Formation of Gas and "Boiling" Action.*—It is the writer's opinion that in the majority of cases "foaming" is but the outward manifestation of a very active sludge. It may be caused by storage of solids capable of undergoing active digestion, which solids begin to digest violently due to an increase in temperature or other favorable conditions.

At Fort Atkinson, Wisconsin, the sewage treatment plant was started in cold weather (as invariably is the case) with the result that solids were added to a digester the contents of which remained at approximately 40° F. for a prolonged period. With the approach of warm weather a pronounced "foaming" took place.

The outward appearance of "foaming" is caused by the lifting of the scum on the surface of the tank by the gas which is attempting to be released from the digesting mass.

Coulter (34) indicates that "foaming" occurs only in connection with very vigorous gasification, and is especially prevalent with restricted gas vent area.

Imhoff (5) states that he has observed that foaming may take place after the ripening period and without acid fermentation, and Rawn (10) states that although factors in connection with "foaming" in separate tanks under his observation have not been determined, acidity apparently is of no importance.

Further observations of the experiences of others indicate that two types of foaming are encountered—namely, foaming under acid and under alkaline conditions. Riker (26) found at Princeton, New Jersey, that in a separate digestion tank, "foaming" took place when the pH was over 8.0.

Welch (25) relating foaming experiences at Flint, Michigan, in 1933 stated that the action was limited to the scum layer of the Imhoff tanks, where the pH was 7.0, and that there was no sign of the disturbance of the lower sludge zone. In former years the "foaming" disturbed the sludge throughout the tanks.

Hatfield (23) indicates that on one occasion at Decatur, Illinois, the pH of his Imhoff tanks was 6.4 to 6.6 before tanks began to foam, and that it remained this low for three to four months after liming and after "foaming" had ceased. Curves plotted for two years of operation at this plant showed no relationship between the pH and "foaming" when observed in the liquor above the sludge. Titratable acidities of the sludge liquor at Decatur, in general, were low when the tanks were not foaming, and high when foaming, but sometimes this did not hold. A normal increase above normal acidity indicated possible foaming, but not with certainty.

Decatur's normal phenolphthalein acidity has been between 200 and 500 p.p.m. and to bromthymol blue 150 to 400 p.p.m., expressed as $CaCO_3$. "Foaming" has taken place with acidities as low as 150 to 200 p.p.m. and as high as 1,000 p.p.m. during foaming. There have also been periods with no "foaming" with acidities as high as 400 to 600 p.p.m.

Hatfield found his best correlation with alkalinities to methyl orange expressed as $CaCO_3$ indicating that same have always been abnormally high during "foaming." Normal alkalinities have run less than 1,000 p.p.m. just before foaming, and during foaming have run as high as 2,500 p.p.m. Hatfield further states that there have been exceptions, with "foaming" occurring with low alkalinities, but that a reasonably good correlation may be shown between high alkalinities and "foaming."

3. *Objectionable Organisms in the Sewage and in the Solids Settled from Same.*—It has been suggested by some observations that certain organisms may be responsible for "foaming" tendencies, with indica-

tions that responsibility for acid production in the early stages of digestion might be laid to organisms of the *B. coli* group.

Cohen (1) states that "foaming" may be due "to abnormal physiochemical conditions of materials in gas vents in connection with a quantity and quality of gas resulting from certain predominating types of organisms or bacteria." Cohen forms the above opinion after success in stopping "foaming" at Lufkin, Texas (where the pH of the foam was from 7.0 to 8.0), by the application of chlorine to the raw sewage. A dosage of 20 p.p.m. was first tried with good results—the black liquor in the flow channels became white and milky due to the release of H_2S and the deposit of finely divided sulphur.

Liming of the same tanks was unsuccessful in stopping "foaming" and gave only temporary relief. Chlorine applied to the sludge compartment met with failure in stopping "foaming," similar to findings at Fort Worth and Dallas, Texas. Returning to a dosage of 6 p.p.m. applied to the raw sewage again gave good results, but a stoppage of the dosage to make repairs caused foaming to start again within ten days. It stopped again in twenty-four hours with the resumption of a 6 p.p.m. dosage. It was found that the dosage of chlorine could be reduced to 3 p.p.m. and be continued only for the period from 8:00 A.M. to 5:00 P.M.—dosage being based on the average flow for that period. The same results were verified at Breckenridge, Texas, and Cohen's explanation was that the chlorine exerts a selective killing action on living organisms.

West (15) reports that in 1932 at the South Side Plant at Stockton, California, continuous difficulty had been experienced with "foaming" which was accentuated during the canning seasons. Chlorination at 3.5 p.p.m. for sixteen hours per day carried out in one of two tanks showed a decided improvement within ten days. The dosage was increased to 4 p.p.m. on a basis of twenty-four hours per day with a noticeable improvement in the settling action also.

4. *Character of the Sewage Such as the Predominance of Objectionable Products Such as Laundry, Cannery, Brewery Wastes, Etc.*—Eddy (29) suggests that if the water supply is hard, insoluble soaps may be formed, and if they constitute a substantial increment in the suspended solids of the sewage may favor the formation of foam and scum.

Trades wastes may increase the viscosity or surface tension of the liquid with possible tendencies in connection with "foaming" which will be discussed later. A stale sewage or one containing pickling wastes may promote an acid tendency and start "foaming" when the sludge is being digested.

5. *Departures of pH from Normal.*—It has been suggested that as a result of the lowering of pH, considerable CO_2 is produced when reacting with carbohydrates present.

Eddy (29) states that "perhaps certain kinds of action such as fermentation with production of large quantities of CO_2, do not as rapidly disintegrate, gasify and render soluble the coarser organic substances as other varieties of action. Therefore there may be an abnormal accumulation of scum-forming solids tending to overload the scum compartment, or to form gas-lifted masses in such quantities that excessive scum formation is inevitable.

Hatfield (23) finds that when digestion is normal the CO_2 content of the gas is less than 20 per cent—between 20 and 25 per cent conditions may be satisfactory—and during "foaming" the CO_2 content has been above 25 with a maximum of 33 per cent.

6. *Marked Viscosity of the Liquid or Scum and also the Mechanical Action of Gas Attempting to Escape Through Scum Having a High Surface Tension.*—Coulter (35) states that from observation he has come to the conclusion that "foaming" and related difficulties arise from a combination of high viscosity of the liquid and the concentration of the escaping gases at the surface. He states that solids kept in constant and intimate contact with highly unstable organic matter undergo vigorous decomposition and the liquid tends to take larger quantities of matter into solution and becomes viscous. When in contact with the rapid escape of gas at the surface this viscous liquid creates a foam. "Foaming" is somewhat analagous to "priming" or "foaming" in steam boilers where anything prevents the free escape of steam from the water, and the principal cause is believed to be an excess of dissolved matter which increases the surface tension of the liquid. Oil on the surface will also increase the surface tension and cause "foaming" or "priming."

Eddy (29) states that at some plants gas rising in the vents has produced a light voluminous foam, due to tenacious films enclosing the gas bubbles.

Buswell, according to recent correspondence on the subject, indicates that foam and scum are distinctly different conditions. Scum results merely from the rising of lighter material to the surface, where, due to its own buoyancy, it lifts out of the liquid and becomes compact and dry. Foam, on the other hand, is due to the upward passage of gas bubbles through a liquid under such conditions that the bubbles do not break at the surface. Colloidal materials such as soap, etc., are always much more concentrated at the surface of a bubble than they are in the body of a liquid. He goes on to say that the principal reason for a stable foam is that the film is more or less viscous, and therefore it does not flow downward to such a degree that the remaining film becomes very thin and breaks.

Buswell further explains that "surface tension" has been wrongly considered as a determining factor in the stability of a foam, and that actually experiments have shown "surface tension" to have little to do with foam stability. The stability is due to a concentration of materials in the foam which cause it to be tough and viscous.

7. *Character of Raw Solids Loading.*—The return of humus sludge from a secondary settling tank may cause "foaming." This condition prevailed at Urbana-Champaign, Illinois. Recent correspondence with G. H. Radebaugh the Plant Superintendent, indicates that to reduce

"foaming" to a minimum, especially in the spring time, he returns humus from his secondary tank during the period of reduced flow at about 10 P.M. The humus goes into the influent channel feeding four Imhoff tanks, it being the idea to distribute the solids equally to all tanks. It was found, however, that Tank 4 foamed while Tank 1 did not foam. The light humus sludge had been carried to the end of the channel by the velocity of flow and loaded Tank 4 more than the others. In 1930 Radebaugh (20) indicated that while 1,380 yards (45 beds) of sludge were drawn, some 450 yards (15 beds) of scum were removed from the tanks.

The addition of a large quantity of grease from newly constructed grease separation tanks at Springfield, Illinois, caused violent "foaming" to take place. By carefully controlled loadings, however, the operator reports they are able to add the grease to the digesters.

8. *Restricted Area of Gas Vents.*—Coulter (35) states that foaming is intensified by small vents or vents restricted by relatively large amounts of scum, while Eddy (29) in comparing the relative operation of a number of Imhoff tanks states that "evidence is so meager and conflicting, that a final conclusion regarding the comparative merits of a small and a large proportion of gas vent area is not justified."

Mohr (30) suggests a modified Imhoff tank with a submerged flowing-through compartment, giving the entire enlarged surface of the tank for scum. He states that the rising gas-filled scum requires a certain area of surface to release the gas.

PROPHLYTICS AND REMEDIES FOR "FOAMING"

Operators are more interested in what can be done to relieve "foaming" in a tank than what causes it to take place. Although the writer has already indicated certain remedies, it might be well to outline those which have been suggested to relieve "foaming."

(*A*) *Care in Maintaining Proper Balance of Raw and Digesting Solids.*—Completely digested material should be removed to prevent use of space required for digestion. Sludge which is digested sufficiently should be removed frequently, but in small quantities.

M. W. Tatlock, Plant Superintendent at Dayton, Ohio, states that he obtains the best results with the Imhoff tanks when he keeps the sludge level up near the slots, drawing small quantities of sludge at frequent intervals. Hatfield (23) agrees with this procedure as long as the sludge which is retained in the tanks is still active, and not inert.

(*B*) *Draw All Sludge from Tanks and Start Anew.*—Hatfield (23) recommends this procedure, stating that the sludge in a foaming tank is infected material and the sooner it is gone the better. The writer would question the feasibility of this procedure, except for an unusual situation.

(*C*) *Addition of Lime.*—We find a great divergence of opinion on the use of lime to eliminate foaming. Eddy (29) reports that the use of lime in the sludge compartment sometimes reduced and sometimes increased the tendency to foam. Walraven (12) states that liming was not effective at Springfield, Illinois, and Imhoff (5) also says liming is not so reliable.

Cleland (11) reports the addition of 200 lb. of lime per million gallons of sewage to maintain a pH of 6.7 at State College, Pennsylvania. He also states that the addition of 55 lb. of lime per 1,000 gallons of sewage effected a reduction of 2 ft. in the scum layer during a foaming period.

Agar (18) reports aid in correcting a foaming condition by the addition of lime at the rate of 10 lb. per 1,000 population per day, adding it directly to the scum layer in the gas vents.

Hatfield (23) indicates that the addition of lime retarded foaming but did not stop it. One of his tanks receiving lime stopped foaming only a few days before an unlimed tank stopped foaming. He feels that the quantities of lime required are prohibitive when a large amount of sludge is present in the tanks.

(*D*) *Chlorination of Sewage.*—As stated in detail before, Cohen (1) reports marked success in stopping "foaming" with a dosage as low as 3 p.p.m. of chlorine added to the flow channel of an Imhoff tank during the period from 8:00 A.M. to 5:00 P.M., while West (15) indicates the use of 4 p.p.m. during a twenty-four hour period.

(*E*) *Allow Tanks to Remain Idle Without any Unnecessary Agitation.*—It has been suggested that a foaming tank should be taken out of service and allowed to rest. It would appear to be more feasible to keep the tank in service and to accomplish the same result by lessening the loading.

(*F*) *Break up Scum in Gas Vents by Mechanical Churning.*—This procedure has been tried in most cases but gives only temporary relief by releasing entrained gas. It is very ineffective when consideration is given to the amount of labor expended.

(*G*) *Remove Scum from Gas Vents.*—Removing the scum may give relief, but it is an undesirable practice. Wilson (37) reports that 90 to 95 per cent of the scum at Bloomington, Illinois, is volatile matter and is readily digestible.

(*H*) *Saturation of Scum with Liquor.*—Hosing of the scum in the gas vents has been quite widely used as a means of breaking up the foam and releasing gas. Buswell suggests a more satisfactory scheme of saturating the foam or scum with liquor drawn from the clear portion of the digestion chamber, the theory being that the slow circulation of this liquor, which is more dilute than the foam, tends to reduce its viscosity and allows the entrained gas to be released. This method has been successfully used at the Urbana-Champaign, Decatur and Bloomington, Illinois, plants.

(*I*) *Submergence of Scum.*—The submergence of scum results in a lessening of the viscosity, as explained above, and releases the gas, allowing the solid material to sink to the bottom.

(*J*) *Heating of Contents at Start.*—In most cases "foaming" may be prevented in a digestion tank just being started, by bringing the contents of the tank up to optimum temperature by heating with an auxiliary means, so that digestion will be started, rather than to allow solids to lay over to undergo violent digestion at a later time, with possible "foaming."

CONCLUSION

In concluding we may say that a digestion tank seems to be able to take quite a good loading—but when it starts to foam, the load must be greatly reduced before it will recover.

Observation of actual digester operation indicate to the writer that in the majority of cases the term "foaming" is applied to the outward appearance of a digestion tank in which the digestion is proceeding at a very rapid rate—generally following a period of retarded digestion brought about by conditions which have not been favorable to normal digestion; such as an abnormally low temperature, heavy loading of raw solids, etc.

Reasonable care should be exercised in the operation of a digestion process, so that balanced conditions are maintained at all times.

Welch (25) likens a foaming tank to a boil—it must come to a head before subsiding.

Hatfield (23) states that a properly designed Imhoff tank will give good results even when foaming badly, as long as the flowing-through chamber is properly baffled.

DISCUSSION

C. F. Tennant (*Los Angeles Sanitation District*): I disagree with most of the remedial measures offered. Having tried most of them without success, I have become very skeptical. In my experience I have seen foaming occur at both high and low pH. During the operation of an experimental digestion unit of four stages, foaming never occurred in the first stage, usually in the second or third, and occasionally in the fourth. This experimental unit had 100,000 gallons capacity or more per stage, was unheated and was entirely open at the top. The sludge in these open tanks has been known to rise as much as 3 ft. in twenty minutes and to subside almost as rapidly. The cause for foaming was present before foaming appeared, but what touched it off is unanswered. Restricted gas outlets may appear to cause foaming if they are of insufficient size to release the gas readily from an active tank.

Foaming is a very difficult thing for an operator to handle. Since the fundamental causes are not yet understood, effective remedies can not be applied. But when foaming occurs the operator must do something and measures of relief must be provided, such as lowering the surface of the tank, hosing the slots or, in the case of covered tanks, circulation of the liquor through top inlets.

Liming of the tanks has been tried by us without success. Spraying the surface of the foam with kerosene or gasoline to reduce the surface tension has also been tried without success. Adjustment of the sludge level in cases of severe foaming has appeared to have no bearing on the situation. The normal scum of the tank in periods of excess foaming is so intimately mixed with the foam that it is difficult to say whether the action is in the scum itself or the mixing is a result of vigorous action from below. In the case of open top tanks, lawn sprinklers can be used to some advantage.

There is one point that has not been touched in this discussion and that is temperature. Both the experimental unit to which I refer and the permanent four-stage digestion unit now in operation have experienced their worst periods of foaming at lower temperatures, usually between 70 and 75° F. The permanent digestion tanks now in use operated several years without foaming in excess of the head room provided. As the sewage flow has increased, the load placed upon the digestion tanks has reached a point where during the winter it is difficult to maintain the optimum digestion temperature of 85° F. Last winter with the temperature of the sludge around 70° F., serious foaming was experienced. I am strongly inclined to the belief that temperature is an influence.

R. A. Stevenson (*Consulting Chemist*): In 1932 some experimental chlorination activities were carried out at the Stockton plant. Three to four parts per million of chlorine were applied to the raw sewage at the entrance to the Imhoff tanks. There was an excessive amount of finely divided material in suspension, and the total chlorine demand was about 22 p.p.m. Immediately there was an improvement in the foaming condition, with consequent clarification. The startling thing was the improved clarification of the sewage. Also there was less gasification in the lower compartment. My theory, which seems to be substantiated, is that the chlorination of the organic particles destroyed their tenacious nature and the ability to form a tenacious film. You might ask Mr. Pomeroy if he can offer any further explanation.

Richard Pomeroy (*Chemist, Los Angeles Sanitation District*): Before answering Mr. Stevenson's question, I would like to make a few remarks on the subject of Mr. Schlenz' paper.

In discussing the theory of foaming, some mention was made of the surface tension and viscosity of the sludge liquor. These factors have very little effect on foaming. I am glad that Mr. Schlenz included the quotation from Dr. Buswell in his truly scientific explanation of the phenomenon. Certain colloidal materials or dissolved materials of high molecular weight tend to concentrate in the surface film—in the thousandth of an inch of the liquid nearest the surface. They thus form viscous films, which do not break, even though the viscosity of the body of the sludge or liquor may be low.

We need to distinguish between the actual condition of foaming and a state of the sludge favorable to the formation of foam. The sludge may have a composition favorable to foaming, but if the gas production is low and the bubbles have room to break or are broken mechanically, foaming may not manifest itself. In the digesters of the Los Angeles County Sanitation District the tanks are divided by baffle walls into separate bays. The composition of the sludge must be nearly the same in different bays, and yet sometimes one bay will foam while another does not. But when one bay or one tank foams, we know that at any moment another bay or tank may foam. The conclusion is that all of the sludge has a composition favorable to foaming, and only awaits the proper mechanical conditions. On the other hand the gas production may be high and there may be a thick layer of floating scum and yet no foaming. I have seen scum with 16 per cent of solids produce gas at the rate of 5 cu. ft. per day per cu. ft. of sludge, yet with no foaming.

If the sludge has a tendency to foam, breaking of the foam by mechanical means will give temporary relief, but this does not remedy the cause. The tendency to foam is probably caused by the nature and concentration of the colloids in the sludge liquor. In composition these colloids are so complex that we have little hope of identifying them by analytical methods. Their variable nature is probably determined by the types of micro-organisms which are active. We may expect that these in turn will be influenced by the seeding material and its proportion to the raw sludge, the composition of the sludge and liquor, the stage of digestion, and the temperature. Thus it is to be expected that there would be some relationship between temperature and frequency of foaming trouble, as has been suggested by Mr. Tennant.

With regard to chlorination, if enough chlorine could be diffused through the sludge it would probably have some effect on foaming, for better or for worse, either by affecting the micro-organisms or affecting the colloidal particles directly. Again, if chlorine is fed continuously to the sewage it would ultimately affect the composition of the sludge and the micro-organisms in the sludge. But it is hard to see how 3 or 4 p.p.m. of chlorine in the sewage could change the character of the whole sludge mass in one day. Maybe it does, or again maybe the apparent correlation quoted by Mr. Schlenz is accidental.

The tanks of the Los Angeles County Sanitation Districts were operated for four years without foaming trouble. The tanks did foam, but the free space between the sludge level and the cover—6 ft. in the first stage and 4 ft. in successive stages—was enough to accommodate the foam. Then in February, 1936, we had a serious siege of foaming in which the foam several times came clear to the top and filled the gas lines, or poured out of the port holes (if we got the port holes open soon enough). Chemical analyses did not show any significant differences from previous results except that the sludge from the last stage was less advanced in digestion, presumably because of lower temperatures. Volatile organic acids ran as high as 800 p.p.m. and bicarbonates down to 2,700 p.p.m. as CO_2. It was thought that the trouble might be due to the fact that for seed sludge we were using poorly digested sludge, which had had only eight to ten days digestion at about 76° F. Consequently older sludge from the storage pit—about two weeks older than that from the digesters—was tried. Foaming subsided. Then in an attempt to determine if this represented a real correlation or an accident, we started seeding one of the two batteries of digesters from the pit and the other battery from its own last stage. We have been doing this for six weeks and have observed no difference in the behavior of the two batteries. Neither is foaming and both are digesting the sludge equally well. However, the sludge from the digesters, used to seed the one battery, is now better digested than was the case in February so the original theory may be right, although there is nothing to prove it.

With regard to the ratios of new sludge to digested sludge, which Mr. Schlenz has stressed, it is significant that in our multi-stage digesters we get satisfactory operation by adding only one part of seed to four parts of raw sludge.

In view of the fact that there is no sure-fire way yet known to prevent sludge from occasionally getting in the mood to foam, it is of great importance that tanks be made to take care of the foam. In my opinion, a good deal of credit is due to the men who designed the tanks at the Los Angeles County Sanitation Districts plant, for they allowed enough head room to take care of any ordinary cases of foaming.

A. J. Smith (*Consultant, Pasadena, California*): I recall, as you perhaps all will, during childhood days, trying to make soap bubbles. Is seems to me there is a very apt comparison between soap bubbles and foaming such as we are now discussing.

My opinion is that grease is back of most of our foaming. The alkalinity of the water turns the grease into soap. Then we have the bacterial action to produce the gases to get the bubbles. Since we installed the grease removal tank at the Whittier Plant there have been no cases of foaming.

E. A. Reinke (*California Dept. of Health, Berkeley*): It seems we should hear some questions from the operators: What is the operator going to do? Occasionally you will find a duplicate sludge pump or a duplicate chlorinator but rarely will you find a duplicate digester unit or Imhoff tank. Most of our experiences have been that where there is room enough you don't have trouble with foaming. One community placed digestion tanks in operation and had no difficulties for about three months, and then the tanks foamed vigorously. After considerable investigation we blamed it onto a little fish cannery and made them quit putting fish wastes into the sewer. Strangely enough the tanks foamed again the next year! As a result of further investigation we learned that all during those days of foaming there was a large winery on the outskirts of the town which had been hooked up to the plant (without the knowledge or consent of the authorities). Well, the plant wasn't designed for a big winery.

F. S. Currie (*Consultant, San Bernardino*): The San Bernardino plant was placed in operation in February, and in June it foamed a great deal. We emptied the tanks and started them up again and we haven't had any bad foaming since. Ontario tanks foamed when first put into operation, Colton, likewise. Most of the plants are put in operation in the winter time when temperatures are low. A big load is built up before digestion gets under way and that causes foaming.

Mr. Ely (*Operator, Ontario Plant*): Last fall I had seven or eight remedies given me for foaming and no two agreed. We started about the middle of July, 1935, with no seed sludge. By the middle of September gas production was well started. Our normal gas production is 17,000 cu. ft. per day. By the middle of October the gas production was above this figure due to digestion of the accumulated sludge. Then we began to have foaming trouble. Our remedy was to open the outlet at the bottom of the digester tank and let the sludge go until scum stopped coming over the top. We worked this system for six weeks. We didn't drain a tank and didn't put in lime. I'd simply turn the valve everytime and the sewer farm got it. At one time when I went to take the temperature I had to plumb down through 12 ft. of foam in the top of the tank to reach real sludge. We started in at a temperature of about 82° F. When it was foaming well it was 93° F. We reached a peak gas production of 60,000 cu. ft. of gas per day. The quality of the gas was reduced so we used as high as 15,000 cu. ft. in the engine instead of about 11,500 as at present. As the temperature and gas production receded, our foam receded. When the foaming stopped we turned on the city water and raised the tank so as not to lose the gas seal. We have had no foam since that time. In the winter we started out to see how much gas we could make by loading the tank with orange pulp, as you have heard. We raised the gas production to 45,000 cu. ft. per day—as high as it was during most of the foaming period—and the results were very satisfactory.

Outline Formulated by Dr. W. Rudolfs

Digestion of Fresh Sewage Solids

(Neither well-digested sludge nor lime being added)

I. *Period of Intensive Acid Production*
  (*A*) *Materials attacked*
    1. Easily available carbohydrates (sugars, soluble starches, cellulose)
    2. Soluble nitrogenous compounds.
  (*B*) *Organisms responsible: B. coli* group, spore-forming anaerobes.
  (*C*) *Characteristics*
    1. Increase in acidity
    2. Solids: gray, less than half on top
    3. Odors: putrefactive, H_2S
    4. Liquid: fairly clear to slightly turbid
    5. Slight coagulation of colloidal material with heat and alcohol
    6. Disappearance of protozoa
    7. Increasing B.O.D. values.
  (*D*) *Products*
    1. Ogranic acids, H_2S
    2. Gas: comparatively large volume with high percentage of CO_2 and N_2.
    3. Acid carbonates.

- (*E*) *pH range:* 6.8 to 5.1.
- (*F*) *Results*
  1. Reduction of colon organisms
  2. Retardation of proteolysis.

II. *Period of Acid Regression or Acid Digestion*

- (*A*) *Materials attacked*
  1. Organic acids
  2. Nitrogenous compounds.
- (*B*) *Organisms responsible:* not definitely determined.
- (*C*) *Characteristics*
  1. Prolongation of the low level of pH values followed by a slow rise
  2. Solids: gray to yellowish-brown, half to four-fifths at top
  3. Odors: H_2S, indol, onion (mercaptans)
  4. Liquid: slightly turbid (milky) to yellow
  5. Some to considerable coagulation of colloidal material with heat and alcohol
  6. High B.O.D. values.
- (*D*) *Products*
  1. Gas: small volume, with decreasing percentage of CO_2 and N_2; hydrogen formed
  2. Ammonia compounds (amines, etc.)
  3. Acid carbonates.
- (*E*) *pH range:* 5.1 to 6.6 or 6.8.
- (*F*) *Results*
  1. Gradual rise of pH curve
  2. Acceleration of digestion
  3. Foaming.

III. *Period of Intensive Digestion of More Resistant Materials*

- (*A*) *Materials attacked*
  1. Nitrogenous materials
     - (*a*) Proteins
     - (*b*) Amino-acids, etc.
  2. Ligno-cellulose (?).
- (*B*) *Organisms responsible:* spore-forming anaerobes, and fat-splitting organisms.
- (*C*) *Characteristics*
  1. Decreased acidity
  2. Increased alkalinity
  3. Slowly rising pH curve
  4. Solids: dark brown to black, half to none at top
  5. Odors: odor associated with methane; tarry, rubber
  6. Liquid: slightly turbid to clear
  7. Some to no coagulation with heat, slight to no coagulation with alcohol
  8. Reappearance of protozoa
  9. Rapidly decreasing B.O.D. values.

(*D*) *Products*

1. Ammonia and other protein degradation products
2. Organic acids
3. Gas: large volume with high percentage of CH_4, low CO_2 and N_2, and no H_2.

(*E*) *pH range:* 6.9 to 7.4.

(*F*) *Results:* sludge stable enough for disposal.

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TREATMENT OF SEWAGE CONTAINING MILK AND BREWERY WASTES AT HIGHLAND, ILLINOIS

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The small but thriving City of Highland, Illinois, of about 3,500 population, located 30 miles northeast of East St. Louis, has been faced with one of the most difficult sewage-treatment problems in the entire State. Troublesome factors encountered in the development of sewage-treatment facilities included a raw sewage containing about 55 per cent milk-plant wastes, an intermittently dry outlet stream and an extremely critical plant site. Further complications in operation resulted after the new plant was completed, when the repeal of prohibition brought about the rehabilitation of a brewery which imposed an additional load on the treatment works.

In response to vigorous complaints by farmers and fishermen to the State Sanitary Water Board in 1930, an investigation was made and objectionable pollution was found to persist for 15 miles downstream from the city. Immediate abatement of the pollution was requested by the Board.

At this time an Imhoff tank and sludge beds comprised the only sewage-treatment facilities and little or no benefit was derived because the milk wastes caused the tank to foam nearly continuously.

Preliminary Studies

In response to the request for abatement, the Caldwell Engineering Company of Jacksonville, Ill., was engaged by the city to prepare a preliminary report on the existing sewerage facilities and the necessary improvements. Preliminary investigations were made in May, 1931, by representatives of the consulting engineering firm, accompanied by the writer. The principal findings and recommendations to the consulting engineer, based upon these investigations follow:

1. The average dry-weather sewage flow of about 300,000 g.p.d comprised about 140,000 g.p.d. of domestic sewage contributed by a population of 3,000 persons and about 160,000 g.p.d. of milk wastes from a large bottling plant (St. Louis Dairy) and from another plant (Highland Dairy Farms) manufacturing butter, cottage cheese and other products. The milk wastes were principally wash water from cans, bottles, floors and equipment although the wastes evolved in washing cheese were also included. Ordinarily very little whey, skim milk or buttermilk were discharged to the sewers, these wastes being disposed of to farmers. Analyses of composite samples of the milk wastes and of the city sewage containing those wastes are shown in Table I. The samples were collected during a very dry season and at a time when the Imhoff tank was foaming.

TABLE I.—*Analyses of Milk Wastes and Sewage at Highland*

Samples Collected May 19, 1931
Analyses by
State Sanitary Engineering Laboratory

	St. Louis Dairy Co. Wastes	Highland Dairy Farms Wastes	Raw Sewage to Imhoff Tank *	Effluent from Imhoff Tank †
Organic nitrogen (p.p.m.)	14	34	60	80
Oxygen consumed (p.p.m.)	115	227	139	189
Solids (p.p.m.)				
Total	1521	1510	1481	1777
Volatile	778	916	812	1025
Total alkalinity (p.p.m.)	760	335	470	540
5-Day B.O.D. (p.p.m.)	440	1000	850	1100
pH	8.8+	8.8+	8.5	6.3

* Includes milk wastes.

† Negative efficiency caused by violent foaming in tank.

2. The existing Imhoff tank was wholly unsuited as a primary treatment unit for the sewage and milk wastes. While the raw sewage was fresh and alkaline upon reaching the tank, acidification took place very rapidly in the unit, no doubt because of the large non-flowing volume containing sour sewage. It is not unreasonable to assume that the acidifying bacteria were always present in large numbers, thus accelerating the souring of the fresh sewage. Separate sedimentation and sludge digestion was, therefore, recommended to avoid this difficulty in the new plant.

3. As the character of the outlet stream made complete treatment essential, trickling filters were selected for secondary treatment, based upon experimental work in milk waste treatment in Ohio, Wisconsin and Michigan. It was recommended that the filter be designed for a reasonable future population plus additional volume calculated on the basis of 60 cu. ft. of stone per pound of milk solids in the daily flow of waste.

4. It was appreciated that the successful use of trickling filters for milk wastes required that the sewage be fresh when applied. Therefore, care was suggested in the design of preliminary treatment units to provide flexibility and to avoid overlong retentions in the presence of accumulations of stale sewage and milk waste.

5. In order to protect the city against unduly great volumes and strengths of milk wastes it was requested by the Sanitary Water Board that a written agreement with the milk companies be submitted before the permit for the plant was granted. The agreement was to state the maximum flow and strength of wastes to be discharged, as well as to provide for equalization of flow and preliminary treatment of the milk wastes if such was found to be necessary. Each dairy also agreed to pay $5,000 toward the construction cost of the plant.

6. The existing Imhoff tank was critically located in a park and golf

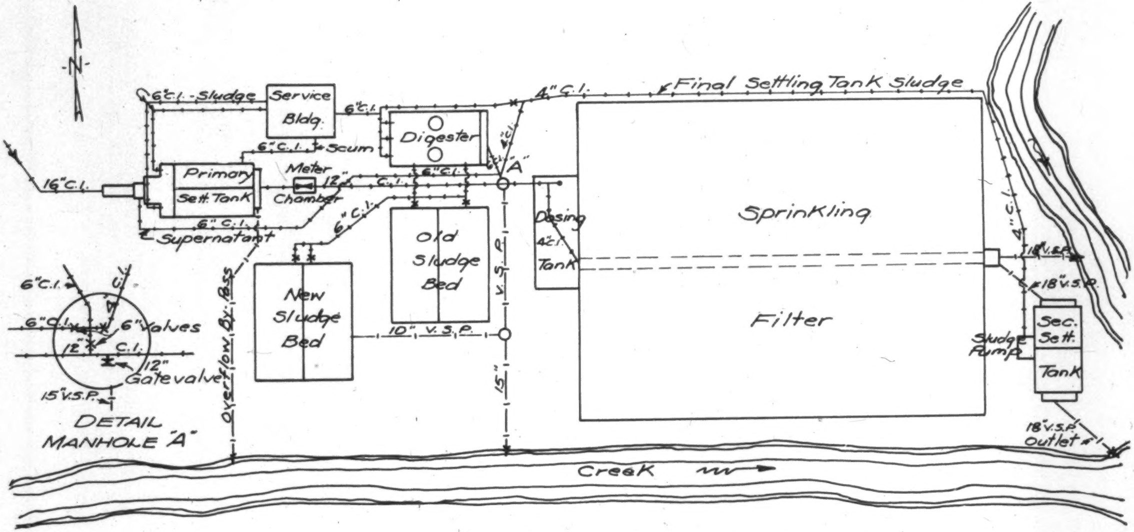
N
16" C.I.
6" C.I. - Sludge
Service Bldg.
6" C.I.
Digester
6" C.I.
Scum
Primary Sett. Tank
Meter Chamber
12"
C.I.
6" C.I.
6" C.I.
Supernatant
6" C.I.
4" C.I.
"A"
4" C.I.
Final Settling Tank Sludge
Dosing
4" C.I.
Tank
Sprinkling
Filter
Old Sludge Bed
New Sludge Bed
10" V.S.P.
V.S.P.
15"
Overflow By-Pass
4" C.I.
18" V.S.P.
18" V.S.P.
Sludge Pump
Sec. Sett. Tank
18" V.S.P. Outlet
Creek
6" C.I.
C.I.
6" C.I.
6" Valves
12"
C.I.
12" Gatevalve
15" V.S.P.
DETAIL MANHOLE "A"

FIG. 1.—Layout of sewage treatment works, Highland, Illinois.

course but after taking all factors into consideration it was felt that this was the best available site for further development of sewage-treatment facilities. Chlorination was recommended for insect and odor control.

One redeeming feature of the site is that gravity flow through the entire plant was possible.

Description of Plant

Plans were prepared in accordance with these suggestions by the Caldwell Engineering Company and construction was completed in 1933.

The layout of the plant is shown on Fig. 1. The design was based upon a future population of 4,500 persons contributing 0.32 m.g.d. of domestic sewage plus 0.18 m.g.d. of milk wastes, the latter flow being assumed to take place over a 12-hour period. The present connected population is about 3,000.

Manually cleaned bar screens are followed by two rectangular primary settling tanks equipped with sludge collectors. The combined retention of the tanks at the design flow is only 1.25 hours, which is low as usually considered, but was felt advisable here because of the need to keep the settled sewage fresh. Two units were provided for flexibility.

The old Imhoff tank was equipped with a fixed cover and thus converted into a digester, a volume of 3.33 cu. ft. per capita being available for the design population. Gas is collected and the tank heated by drawing off a small volume of the supernatant liquor, passing it through the boiler and discharging the heated liquor through nozzles in the lower part of the digester. Supernatant liquor is wasted to the raw sewage. The combined area of the old and new sludge drying beds provides 0.7 sq. ft. per capita for the design population.

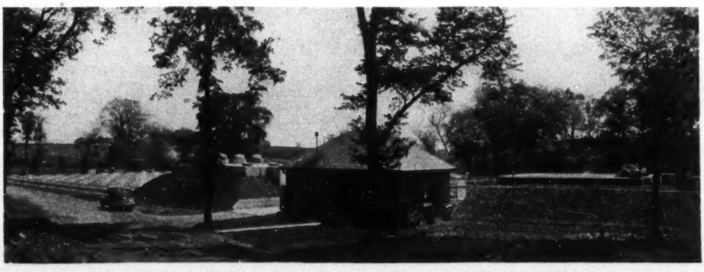

FIG. 2.—General view of sewage treatment works, Highland, Illinois.

The trickling filter has nozzle distribution, has an area of 0.4 acre and is 7 ft. deep. Design was based on a populatioin loading of 3,000 persons per acre ft. in addition to 1.28 acre ft. required for 928 lb. of milk solids per day at 60 cu. ft. of stone per pound solids. Open inspection galleries on two sides provide excellent ventilation.

The hopper-bottom final settling tank affords a retention at the design flow of 1.0 hour. Sludge can be returned either to the inlet of the primary tank or to the digester.

An attractive brick building houses the sludge pumps, heating plant, a small but complete laboratory, office, meters and chlorinator (Fig. 2). Provision was made for the application of chlorine to the settled sewage as it flows from the venturi meter.

The details of the plant were well designed. Credit is due the city officials for the landscaping and maintenance which have made attractive surroundings possible (Fig. 3).

FIG. 3.—Sewage treatment works. Fish-pond in foreground, final settling tank at rear, Highland, Illinois.

OPERATION

A few months after the plant was placed in operation, in the Spring of 1933, the repeal of prohibition brought about the rehabilitation of the Schott Brewery which has a capacity of 350 barrels of beer per day. The wastes, comprising about 40,000 g.p.d. of floor and equipment wash, excess yeast and some spent mash, have been pumped into the city sewers since August, 1933.

The operation personnel of the plant consists of one man, Harold Gnaegy, who does the laboratory work and takes care of grounds maintenance as well as all the other work pertaining directly to operation.

The average sewage flow to the plant was 0.47 m.g.d. during the year 1935. The range was from an average of 0.363 m.g.d. in January to 0.714 m.g.d. in May. Though the sewer system was built for sanitary sewage only, heavy infiltration in some sections and unsanctioned roof and surface water connections cause a considerable increase in flow in wet weather. The present dry-weather flow comprises about 46 per cent milk waste, 45 per cent domestic sewage and 9 per cent brewery waste.

Unfortunately, it is not possible to show comparable data before and after the reception of the brewery wastes because of the lack of complete analyses prior to the time the brewery was put into operation. It was apparent, however, that the brewery wastes brought an appreciable increase in settleable solids, this increase being estimated at about 40 per cent. Some loss of spent grain to the sewers is apparently to be expected at a brewery even though reasonable care is exercised by employees to accumulate this waste product for distribution to farmers.

The analytical data are not so complete as is desired for reporting the results at this interesting plant, although some worthwhile information is available as several composite samples are collected each month for B.O.D. and other determinations in the local laboratory. Several series of analyses of composite samples have also been made in the laboratories of the State Department of Public Health. Because of the wide variation in the character of the sewage, the range is shown with some averages in Table II, the data being taken from the monthly operating reports for 1935.

TABLE II.—*Analytical Summary for Year 1935, Highland Sewage Treatment Works*
From Monthly Operating Reports

Station	Raw Sewage	Primary Effluent	Final Effluent
Settleable solids (ml. per liter)			
Range	Trace–13.0	Trace–2.5	0–0.5
Ave.	5.5	1.2	0.1
pH			
Range	6.8–8.4	6.8–8.4	7.1–8.4
Ave.	7.6	7.3	7.6
Total suspended solids (p.p.m.)			
Range	210–650	110–335	26–74
Ave.	350	180	45
5-Day B.O.D. (p.p.m.)			
Range	290–1090	230–665	19–100
Ave.	491	357	54
Population * equivalent (persons)			
Ave.	12,800	9,300	1,400
Per cent removed	—	27.2	89.1
Methylene blue stability (days)			
Range	—	—	1–12

* Calculated at 0.15 lb. 5-day B.O.D. per capita per day.

A typical series of analyses of composite samples taken through the plant is shown in Table III. The determinations were made in the State Sanitary Engineering Laboratories.

Preliminary Settling Tank.—These units did not require much attention before the brewery wastes were received, the solids removal being fairly satisfactory and a fresh effluent produced. Since the brewery began to operate, considerable spent grain is received, some of which settles in the screen chamber. This material must be promptly removed in order to prevent odors and acidification. The brewery officials have been instructed not to discharge grain to the sewers but there are still occasional lapses.

TABLE III.—*Analytical Results of Highland Sewage Treatment Plant*

Composite Samples Collected October 30, 1934
Analyses by
State Sanitary Engineering Laboratory

	Raw Sewage	Primary Effluent	Filter Effluent	Final Effluent
Free ammonia	11.0	12.0	3.0	2.4
Organic nitrogen	33	24	7	8.9
Nitrites	0	0.12	1.25	0.85
Nitrates	0	0	0	0
Suspended solids				
Total	428	216	57	46
Volatile	384	196	52	40
5-day B.O.D.	710	412	130	76

All results in parts per million.

Consideration is now being given the use of chemical precipitants to increase the primary tank efficiency and thus reduce the load on the filter. Experiments with chlorinated scrap iron are planned for this summer.

Digester and Sludge Drying Beds.—There were also no serious operation difficulties at the digester prior to the reception of the brewery wastes.

The arrangement for heating the tank has not proven entirely satisfactory because of clogging in the pump, even since an open impeller was installed shortly after the plant was placed in operation. The temperature in the digester varies between 55° and 75° F. depending upon the season.

When operation was begun some foaming was experienced and the writer made an inspection, expecting to find the tank in an acid condition from the milk wastes. Investigation revealed, however, that the scum sprinkling system had been connected with the city water supply and was being kept in continuous operation because of the foaming. As this water had a pH of 7.8 to 8.5 due to overtreatment with lime, the foaming was taking place in an alkaline range and was readily corrected by shutting off the sprinklers.

The spent grain which accompanies the brewery wastes has brought the digester to the point of overload so that additional sludge storage and drying bed capacity is now contemplated. In 1935 it was necessary to obtain 9 dryings from part of the sludge beds.

The measured gas production is about 2,500 cu. ft. per day, but it is known that there is considerable leakage of gas due to the failure to secure a tight joint in constructing the concrete cover on the old Imhoff tank. The actual gas production is much higher than that measured.

The supernatant liquor is normally quite concentrated but an appreciable improvement resulted when prechlorination (at screen chamber) was tried in September, 1935. An application of about 10 p.p.m. resulted in a reduction of odors and scum formation at the primary tank as well as improved digester operation. Chlorination of the settled sewage was not carried on at this time but was resumed in the winter of 1935–36 when cold weather prevented prechlorination.

Sprinkling Filter.—The work done by this unit is remarkable when it is considered that the average daily organic loading of the filter is about 500 lb. of 5-day B.O.D. per acre ft., which is about twice the normal loading. The average volume load is about 1.25 m.g. per acre per day.

The single nozzle field required a dosing tank of 14,000 gallons capacity and to arrest possible souring of the settled sewage, an old air compressor is utilized to aerate the dosing tank contents. The air is applied through a perforated pipe grid, the installation being somewhat crude but nevertheless effective, as the sewage applied to the filters is always kept fresh and alkaline. The dosing tank volume was recently reduced to approximately 10,000 gallons without materially affecting the hydraulic characteristics of the unit.

An operation measure which has been found of value is the return of a part of the plant effluent to either the raw or the settled sewage during extreme dry periods when the sewage is very concentrated. This is done by operating the final settling tank sludge pump (centrifugal) continuously, the capacity of the pump being about 25 per cent of the dry weather sewage flow. Any sludge accumulations are removed, of course, before return to the settled sewage. This practice, begun in 1934, resulted in a marked freshening of the sewage, reduction in odors and improvement in the plant effluent. It is regretted that the lack of analytical data prior to 1934 makes it impossible to show comparative data. The plan was suggested by the experience at DeKalb, Illinois, where it is carried on during a seasonal cannery waste load, and it is believed that it has also been used by Mr. Sperry, of Aurora, in experimental investigations.

Despite the critical location of the plant and the nature of the sewage handled, there has been no odor trouble up to this time. Occasionally, a "caustic" odor resulting from the cleaning operations at the milk plants or a "beer" odor caused by the brewery wastes will be noted while the filter nozzles are discharging, but the offensive hydrogen sulphide odors have not been evident.

In March, 1936, an unusually heavy sloughing of the filter took place which was particularly troublesome because of the lack of adequate sludge digestion and disposal facilities. The sludge obtained from the final settling tank was black and putrescent, the condition existing for nearly a month. An abrupt rise in air temperatures within two or three days, just before the slough, may be an explanation.

Final Settling Tank.—This unit has functioned well in removing filter solids but its efficiency is definitely impaired by the extreme fluctuations in the rate of flow induced by the large filter dosing tank.

Chlorination.—Until September, 1935, chlorine was applied only to the settled sewage. The normal dosage of about 4.5 p.p.m. in winter and 9.0 p.p.m. in summer is sufficient to control filter odors.

In the late summer of 1935, the point of application was changed to the screen chamber, where a dosage of about 10 p.p.m. was found to improve primary settling tank and digester operation, as well as to maintain odor control. Residual chlorine is sometimes present at the primary tank outlet with this dosage.

Another chlorinator was installed at the final settling tank in October, 1935, where a dosage of 7 to 12 p.p.m. effectively eliminated all traces of outlet stream fungus growths. This dosage gives a consistent residual of about 1.0 p.p.m. in the effluent.

Plant Effluent and Outlet Stream.—It is not claimed that the effluent from this plant will match the clear, sparkling product of many plants treating a normal domestic sewage. It is not consistently possible to maintain methylene blue stabilities nor would the average B.O.D. of 54 p.p.m. ordinarily be considered good. However, the extremely rigid requirements of that practical test of any plant effluent, the "S.F.C." (Satisfied Former Complainant) determination, have been adequately met as is demonstrated by the unsolicited expressions of satisfaction by the downstream farmers and fishermen.

Even before the effluent was chlorinated, the principal objectionable condition was the fungus growths, which were never present farther than 300 ft. below the outlet. Putrescent conditions were never present and the average dissolved oxygen content 400 ft. downstream was about 3.0 p.p.m. During effluent chlorination, the fungus growths are completely controlled and the dissolved oxygen content downstream is about 6.0 p.p.m.

Costs.—The construction cost of the plant, including the original cost of the Imhoff tank and old sludge beds was $68,000 of which the two milk plants contributed $10,000, leaving a net cost to the city of $58,000.

The operating costs for the year 1935 are itemized below:

Item	1935 Expenditures $	Operation Cost per M.G. Treated $
Labor		
Operator's salary	1230.00	
Extra labor	142.20	
Total	1372.20	7.86
Power (2¢ per K.W.H.)	680.00	3.94
Chlorine	582.44	3.37
Repairs, supplies, etc.	281.99	1.63
	2916.63	16.90

There was no actual expenditure made for the power item shown above because the utility is municipally owned. The item is included, however, at a reasonable charge.

As the brewery made no contribution toward the construction cost of the plant, a charge of $25 per month is made to this industry. Deducting the allowance made for power and crediting the city with the $300 received from the brewery, the actual cost to the city during 1935 was $11.70 per million gallons treated.

SUMMARY AND CONCLUSIONS

While the plant as constructed has proven adequate to meet the present needs, much has also been learned from the mistakes made. It should be remembered, however, that many of the operating problems discussed herein are primarily due to the brewery wastes which were not considered in the design. Based on experience at this plant the following conclusions seem justified:

1. Separate sedimentation and sludge digestion is much better adapted to the treatment of a sewage containing milk and/or brewery wastes than is an Imhoff tank. It is believed that a detention period of up to 2 hours may be used if the sewage is fresh when received. It is also suggested that this period be supplied in two units for flexibility and that the settling tanks be relatively shallow to avoid the presence of non-flowing volumes.
2. The filter dosing tank as built at Highland gives an unbalanced dosing cycle and reduces the final settling tank efficiency. The revolving distributor which has come into general use in the last few years is admirably adapted to a filter receiving a sewage of this type as a small dosing tank can be used and a nearly continuous flow maintained.
3. The method used in determining the required filter volume appears to have given an adequate filter, although not a conservatively large one. The filter would probably do better work if the primary tanks were larger and if the dosage rate were more constant.
4. The return of a portion of the plant effluent to dilute the raw or settled sewage appears very desirable in the treatment of concentrated sewage. Provision for this in the design of any plant of this type is suggested, if for no other reason than for use in the control of filter odors.
5. Adequate chlorination facilities appear justified in this plant and any other installation of such facilities should provide for utmost flexibility as to the points of application.

Acknowledgments.—Information and assistance by Mayor C. H. Stocker and Operator Harold Gnaegy, of Highland, and by J. G. Weart, Chemist, of the Division of Sanitary Engineering, Illinois Department of Public Health, are gratefully acknowledged.

Stream and Harbor Pollution

A STUDY OF THE POLLUTION OF A SHELLFISH PRODUCING AREA *

By Arthur P. Miller

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For many years Raritan Bay † has been a prolific producer of both hard and soft clams. Whether this variety of shellfish was harvested from this area years ago to the detriment of the public health I cannot now say but with our present knowledge concerning the relationship between contaminated shellfish and the incidence of certain diseases, it behooves present day public health agencies to consider more carefully the sources of market shellfish.

Existing Restrictions

The health authorities of New York City recognized the danger in taking clams from the polluted waters of this large area as early as December, 1924, when they closed their markets to all shellfish from them except string clams marked "For cooking purposes only." New York State officials closed the New York portion of the Bay for the taking of shellfish for marketing purposes in 1925 and in 1934 the New Jersey State Board of Health took similar action on certain shore line areas, thereby restricting the taking of clams to those sections which in their opinion were satisfactory. All of these official actions reduced the clamming grounds in the Bay to an area much smaller than was formerly available. On Chart I, I have shown the clamming grounds in Raritan Bay, New Jersey, as they have been described by some of the older fishermen using them today; the areas in the entire Bay which were closed prior to 1935; and the additional area in New Jersey closed subsequent to this study.

Chart I shows this to be a good clam growing area; one which can support a large number of shellfishermen. In Highlands, New Jersey, the taking, shucking and packing of clams is one of the important industries today and the livelihood of many families is dependent upon activities incident to it. There is no inclination on the part of any public health officer with whom I am familiar to insist upon the closure or restriction of any shellfish area which does not merit such action. However, if there is any doubt concerning the quality of an area, a decision must be made against the area and in favor of the public health. The only tenable position—one with which the shellfish industry as a whole will agree, I am sure—is that no chance should be taken when disease, suffering and possibly lives are in one balance with the need for limiting or restricting a local industry in the other.

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* Presented at the Annual Meeting of the New Jersey Sewage Works Association at Trenton, New Jersey, March 19, 1935.

† Raritan Bay as used in this paper will be considered as those areas shown on U. S. Coast and Geodetic *Chart 369* as Raritan Bay, Sandy Hook Bay and Lower Bay.

It was, apparently, with these considerations in mind that New York City through its Board of Health erected a barrier against clams from this Bay by prohibiting their sale in that city. Inability to sell to New York City dealers presented a severe handicap to the shellfish industry along the New Jersey shore of Raritan Bay and warranted relief measures if they could be secured safely. This was the situation in the summer of 1935 when the desirability of this survey was first mentioned. After several conferences by the interested groups, New York City agreed to permit the sale of clams within city limits from those areas in Raritan Bay, New Jersey, found by the U. S. Public Health Service to be suitable for clam harvesting. Having secured such a fair decision, it remained only to ascertain by careful study what sections—if any—of these New Jersey waters were suitable for the removal of clams for direct sale to dealers.

Factors Included in Study

The Report of the Committee on Sanitary Control of the Shellfish Industry in the United States, drawn up and published in 1925, set forth a number of specific recommendations concerning the scope and enforcement of State regulations for the sanitary control of shellfish. One of the essential requirements was stated to be "that no shellfish should be offered for sale except such as have been taken from beds which, after careful and competent examination, are found to be free from any justifiable suspicion of contamination which is judged to be either dangerous or offensive." In discussing the provisions essential to fulfilling this requirement, the Committee outlined briefly how and under what conditions an area should be approved. Its stipulations were as follows:

> ". . . that before approval is given for the use of any area for the taking of oysters for market, the area should be carefully examined by competent and responsible officials.
>
> "The examination of the area should always include a sanitary survey, which should be supplemented by bacteriological examinations of the water and shellfish wherever these may be necessary for competent judgment. Since it is essential that the examinations be made and interpreted only by persons having the necessary qualifications of technical education and experience, it is assumed that the purposes, methods and limitations of sanitary surveys and bacteriological examinations will be understood and need be outlined only briefly here.
>
> "The primary purpose of the sanitary survey is to estimate as accurately as possible the extent of actual or potential contamination of the waters in question with *human excreta*. A distinction must be made between such pollution and that from animal sources or from the soil, as a necessary basis for the interpretation of the results of bacteriological examinations.
>
> "The survey should, therefore, take careful account of all the determinable factors affecting pollution, namely: the sources of actual or potential fecal contamination, with special reference to human excreta, considered in relation to methods and efficacy of artificial treatment of sewage and to the natural safeguards afforded by dilution in the receiving body of water and by natural purification, as influenced by temperature and

> by time intervals between contaminating sources and the shellfish beds, due regard being paid to the likelihood of contamination in coves and inlets from sources which would be insignificant in relation to a large and well mixed body of water. Careful consideration should also be given to the likelihood of dangerous contamination from boats, especially in small and shallow bodies of water and in the vicinity of main ship channels. Any discharge of excreta from oyster boats in the vicinity of shellfish beds should be rigidly prohibited.
>
> "Although the information furnished by a survey of this kind is not exact in a quantitative sense, it will be sufficient for forming a reliable judgment when the examination shows such pollution or risk of pollution as to render the area obviously unfit, or conversely, where it shows that there is no discoverable probability of dangerous contamination. Where the survey shows exposure to more or less constant but probably slight pollution with sewage from rather distant sources, or with surface drainage from populous unsewered territory, so that the safety of the area depends upon the protection afforded by dilution and natural purification, there is need of more exact quantitative information than is furnished by a sanitary inspection alone; and in such cases bacteriological examinations of the waters and shellfish are a necessary part of the study."

Undertaking an inspection such as outlined above consequently involved a study by competent personnel of actual and potential sources of contamination; the results to be summarized in a quantitative way and considered in relation to dilution, tides, currents and time intervals. Such a study necessarily entailed the collection of both physical and bacteriological data.

In my elaboration of this particular study, I will discuss (*a*) the quantities of sewage reaching Raritan Bay and their probable effect on the New Jersey waters thereof; (*b*) the influence of natural factors such as winds and tidal currents; and (*c*) the bacteriological confirmation of tentative decisions reached from the examination of the physical data.

Quantities of Sewage Discharged

Through the coöperation of the Department of Sanitation, City of New York, and the State Department of Health of New Jersey, I have been able to secure approximate figures on the quantities of sewage reaching Raritan Bay either directly or by way of tributary streams. In Table I these data are tabulated divided in two different ways; namely, on the basis of (1) treatment and (2) the receiving body of water. Obviously, these figures include only the discharges from territory lying within a reasonable distance of Raritan Bay.

In New York, treatment as shown in this table consists of fine screens with or without chlorination. In New Jersey, it involves combinations of the processes of sedimentation, oxidation and chlorination, and in most cases is of higher character than treatment at any New York State outlet included.

Available Diluting Water

In the following discussion of available dilution, the treated and incompletely treated wastes will be ignored and only untreated sewage considered. The greatest volume of raw sewage finding its way into the Bay through contributory streams comes from New York State and

TABLE I.—*Sewage Contributed to Raritan Bay (Directly or by way of tributary streams)*

Receiving Waters	Approximate Discharge in M.G.D.			Sources of Waste—In General
	Treated	Incompletely treated	Untreated	
Hudson River	26.0	—	11.0	N. Y. State—Westchester Co.
	—	—	0.5	N. Y. State—Bronx Boro.
	18.0	—	121.3	N. Y. State—Manhattan Boro.
East River	—	—	90.0	N. Y. State—Manhattan Boro.
	—	—	99.0	N. Y. State—Bronx Boro.
	—	—	280.5	N. Y. State—Manhattan and Bronx Boros.
	—	—	15.6	N. Y. State—Queens Boro.
	—	—	102.5	N. Y. State—Brooklyn Boro.
	—	—	117.4	N. Y. State—Brooklyn Boro.
Upper Bay and Narrows	2.2	—	6.3	N. Y. State—Staten Island
Kill Van Kull and Arthur Kill	—	—	13.7	N. Y. State—Staten Island
(Sub-total 1)	46.2	—	857.8	N. Y. State
Shrewsbury River	0.7	0.1	0.1	N. J. State—5 municipalities
Matawan Creek	0.2	—	—	N. J. State—Matawan
Arthur Kill	—	—	41.0	N. J. State—Rahway and Elizabeth Valleys
Raritan River	5.4	4.2	16.3	N. J. State—21 municipalities and private groups
Newark Bay	5.1	13.7	9.0	N. J. State—Hackensack Valley
Upper Bay	—	166.0	—	N. J. State—Passaic Valley
(Sub-total 2)	11.4	184.0	66.4	N. J. State
Total A (1 plus 2)	57.6	184.0	924.2	N. Y. and N. J. States
Raritan Bay	3.3	—	1.1	N. Y. State—Staten Island
	42.0	—	44.0	N. Y. State—Brooklyn Boro.
(Sub-total 3)	45.3	—	45.1	N. Y. State
Raritan Bay	0.8	0.5	—	N. J. State—3 municipalities
(Sub-total 4)	0.8	0.5	—	N. J. State
Total B (3 plus 4)	46.1	0.5	45.1	N. Y. and N. J. States
Grand total (A plus B)	103.7	184.5	969.3	

is approximately 858 m.g.d. With the exception of possibly 14 m.g.d. most of this large amount or 844 m.g.d. passes into the Bay through the Narrows. This seems to be a tremendous volume but when it is compared with the entire flow of water through this section it is not so imposing. In the Report of the Metropolitan Sewerage Commission of New York (1914), a U. S. Coast and Geodetic Survey letter describes a discharge at the Narrows of 105,000 m.g.d. at ebb tide, and 97,500 m.g.d. at flood tide, averaging 101,250 m.g.d. The flow of sewage at this point is, therefore, about 0.84 per cent of the diluting water there. In other terms, there are 119 gallons of diluting water for each gallon of sewage.

There are approximately 55 and 25 m.g.d. of sewage coming from Arthur Kill (plus Newark Bay) and the Raritan River respectively. Although precise figures on the flow of water in these two tributaries are not available, both of them are relatively large with 25 to 40 ft. channels, and unquestionably have sufficient quantities of water issuing from them to give a dilution factor higher than that for the Narrows. The contribution to the Bay from the Shrewsbury River (0.1 m.g.d.) is too small to warrant further consideration. It should be kept in mind, also, that a large proportion of the sewage heretofore mentioned enters the contributing streams at varying distances from Raritan Bay and has received partial natural treatment (dilution and oxidation) before passing into the Bay.

Let us now examine the amounts of sewage entering the Bay directly—because of proximity—a far more important question insofar as shellfish growing areas are concerned. From New Jersey there is no direct flow of raw sewage into the Bay. From New York there is about 1.1 m.g.d. of untreated sewage entering Princess Bay, a small arm of Raritan Bay, and 44 m.g.d. entering Sheepshead Bay. Exactly speaking, this last discharge is not directly into Raritan Bay, being at a point some distance towards the sea from a line drawn between Norton Point on Coney Island to Sandy Hook. However, as these wastes ebb and flood out of and into the Bay they are brought into the discussion.

Summing up the question of raw sewage contributions, we find fairly adequate dilution available for those wastes not directly deposited in the Bay: 1.1 m.g.d. discharged immediately into the Bay on the New York side; and 44 m.g.d. deposited at a point on the same side sufficiently close to Bay waters to have an effect on them because of tidal currents. Although this Bay occupies an unfortunate position for shellfish cultivation on account of the metropolitan character of the surrounding territory, the great volume of water in it seems to afford fair protection to certain selected areas. If only a small portion of these wastes were in direct contact with the shellfish areas under consideration there would have been little purpose in this study but dilution and other factors to be discussed force one to entertain more favorable conclusions regarding their quality.

EFFECT OF CHANNELS

As I have pointed out, the greater volume of sewage entering Raritan Bay does so through the Narrows although smaller amounts also come in from Arthur Kill and the Raritan River. Without considering certain physical factors, one might assume that all of these wastes would mix thoroughly with the entire mass of Bay water. There is, without doubt, some intermingling at the edges of the flow coming through the Narrows from Upper Bay but on the whole it follows a fairly well defined path. The same is true of the discharge from Arthur Kill but not so much of that from Raritan River which tends to mix more completely with the waters in the western end of the Bay.

In my opinion the two principal forces controlling these wastes and working to keep them out of New Jersey waters are the channels and the tidal currents. The Upper Harbor flows carrying the bulk of New York City's sewage tend to move out to sea through Ambrose Channel while those from Arthur Kill seem to follow the 30 ft. channel running from the tip of Staten Island up into Princess Bay and from Seguine Point in that Bay towards Sandy Hook. This tendency was observed on the waters during our traverses of the lines of sampling points and could be recognized through the movements of floating debris.

TIDAL CURRENTS

The evidence on the directions of flow secured through a study of the tidal currents in these waters is more compelling. Special Publication 152 of the U. S. Coast and Geodetic Survey, entitled "Tidal Current Charts—New York Harbor," gives 24 charts, each of which shows the direction and velocity of the tidal currents for its specific tidal hour at Governors Island, New York. The following descriptions are of those charts which produce the most proof to assist this study:

> (1) At low water—Southern Raritan Bay water and that within Sandy Hook is moving to sea. Upper Bay water is, in the main, moving to sea although there is a slight tendency for it to encroach on the New York side of Raritan Bay.
>
> (2) At 1 hour after low water—sea water is moving in pushing the Upper Bay flow over on to the New York side of Raritan Bay to such an extent that there is a current created flowing directly from the Upper Bay across Raritan Bay in New York, around the southern end of Staten Island and up Arthur Kill to a slack point located just north of Staten Island's southern tip.
>
> (3) At 2 hours after low water—the currents at this time are much the same as described for one hour after low water except that the sea water has reached a point farther in Raritan Bay and slack water in Arthur Kill is up to the northwest tip of Staten Island.
>
> (4) At 3 hours after low water—the incoming tide has now reached such proportions that it cuts off the flow from Upper Bay not permitting it to cross Raritan Bay.

A normal tidal current flow is represented by the chart for two hours after high water, a description of which is as follows:

> The flow from the Upper Bay is moving down and out towards the sea at a distance from Coney Island of about half the opening between Coney Island and Sandy Hook, while the flow from Arthur Kill is moving across Raritan Bay, confined right definitely to the northern half, on by Sandy Hook and out to sea.

What can be deduced from this information? First, that depending upon the tide, the sewage coming through the Narrows either flows smoothly out to sea with only its edges intermingling with clean water or is pushed back towards the New York shore to such an extent that it flows westward over Raritan Bay and up Arthur Kill, and second, that the flow from Arthur Kill and to some extent from Raritan River on

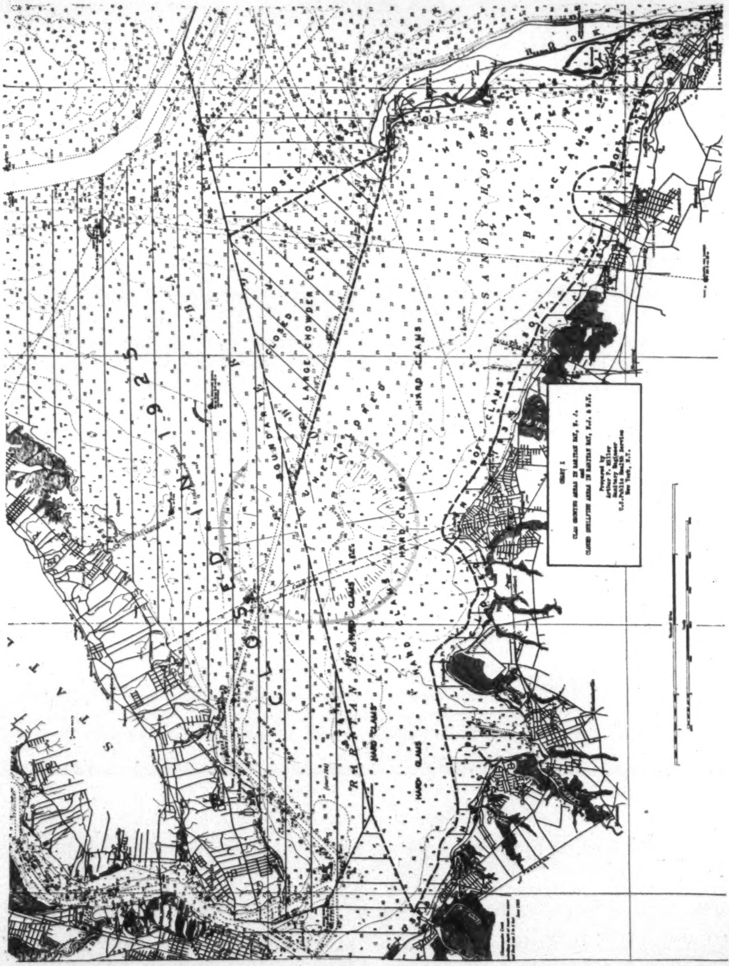

CHART I

CLAM GROWING AREAS IN RARITAN BAY, N. J.

and

CLOSED SHELLFISH AREAS IN RARITAN BAY, N.J. & N.Y.

Prepared by
Arthur P. Miller
Sanitary Engineer
U.S. Public Health Service
New York, N.Y.

CLOSED 1925
SANDY HOOK BAY
HARD CLAMS
SOFT CLAMS
CLOSED LARGE CHOWDER CLAMS
BOUNDARY
RARITAN BAY
SANDY HOOK

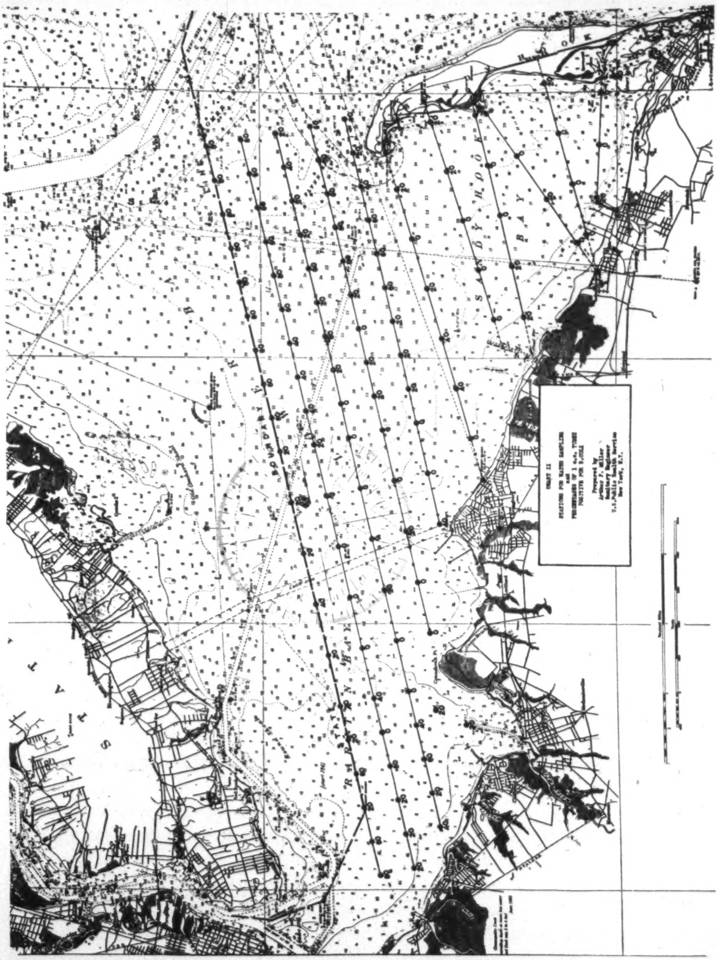

CHART II

STATIONS FOR WATER SAMPLING
and
PERCENTAGES OF 1 c.c. TUBES
POSITIVE FOR B.COLI

Prepared by
Arthur F. Miller
Sanitary Engineer
U.S.Public Health Service
New York, N.Y.

SANDY HOOK BAY
BOUNDARY
STATEN
RARITAN BAY

the flood tide goes northeast into Princess Bay and then directly across Raritan Bay on the New York side and out to sea. Probably more than anything else, these tidal currents help to restrict the New York wastes to New York waters thereby protecting the waters of the New Jersey portion of Raritan Bay.

Reverting now to my summation of the quantities of raw sewage entering directly into the Bay, let us consider them in conjunction with the tidal currents. At Princess Bay, 1.1 m.g.d. is discharged directly. This small volume must be caught up in the tidal current moving from the mouth of Arthur Kill up into Princess Bay and then off towards Sandy Hook. This quantity combined with what comes out of Arthur Kill and Raritan Bay seriously affects the New York side of the Bay but does not seem to spread to such an extent as to reach the bulk of the New Jersey waters. The 44 m.g.d. deposited in the vicinity of Sheepshead Bay is flooded back up through the Narrows or towards Staten Island and then ebbed out to sea. Some of it probably works over towards Princess Bay and to a minor extent in towards Sandy Hook after several ebbs and floods of the tide.

FLOAT STUDIES

The 1914 report of the Metropolitan Sewerage Commission includes a number of charts of float studies made in New York Harbor and adjacent waters. Only one chart of the group showing floats started at various points in the Upper Harbor or outside of Sandy Hook gave evidence that New York sewage might approach as close to the New Jersey side of the Bay as Romer Shoal light. All others supported the theory that but little of the sewage discharged through the Narrows or along Coney Island reaches New Jersey waters in any appreciable amount.

WINDS

Tidal currents when undisturbed by other influences may be presumed to remain fairly consistent in their movements but strong winds have been known to deflect large quantities of water from their normal paths. What then is the history of winds in this area? For the 10-year period 1925–1935, the Weather Bureau reports that northwest winds prevailed in this vicinity during the shellfish season (September–April). For the 20-year period, 1915–1935, the average velocity of the winds was 15.2 m.p.h. which is equivalent to a moderate breeze. From the viewpoint of sewage-polluted waters being pushed over from the New York side on to New Jersey shellfish areas, we have, therefore, winds from about the most favorable direction. However, the average velocity is so low that the results of this force are not disastrous although there is, without question, some measurable deleterious effect.

Having carefully examined the natural or physical factors, a survey of this kind next requires confirmatory evidence obtainable through bacteriological examinations of water samples from the area under inspection.

PLAN AND PROCEDURE IN WATER SAMPLING

Chart II shows the plan of sampling stations prepared in advance of the field work. Lines of sampling stations between fixed shore points are most desirable but in a body of water such as this, such lines can not always be had. Therefore, it was necessary, on the five outer lines which vary in length from 13,000 to 24,000 yards (7½ to 13½ miles), to run by compass and watch, using a boat, the speed of which had been calibrated in advance. The other six lines of sampling points were from fixed objects on shore which could be sighted from a moving boat. In addition, there were a few odd stations identified by objects in the water. Altogether 118 sampling stations were selected and all of them were used. Aside from days of severe weather, the sampling routine encountered no difficulties and on our first regular run of 24,000 yards we checked on a fixed object located at the 22,000 yard point with an error of 100 yards.

The New Jersey State Department of Health conducted most of the sampling work although the writer and his assistant were present on several occasions. Sampling equipment was very simple consisting only of sterile 10 c.c. tubes plugged with cotton and a short stick on the bottom of which was a spring device to hold the tubes in position when forced into the water. The boat's speed, the watch and the chart of stations were checked constantly by one man who was responsible for the sampling. A pilot operated the boat and a third man took the samples when so ordered. Only top water samples were taken.

From May 20 to June 22, 1935, when this work was done, 5 complete runs were made of the entire series of stations. Starting times were calculated each day to insure in the end 5 samples at each station for the following tidal conditions:

(1) High tide
(2) Low tide
(3) Half flood tide
(4) Half ebb tide
(5) Three-fourths ebb tide

By following this scheme rather than just taking samples at times most convenient to the workers, we had at the end of the survey results which were exactly comparable. In other words, the tide intervals between samples at any one station were exactly the same as the tide intervals for samples at any other station. Insofar as I know, this is the only method by which one can secure samples at the same tide intervals when a long series of stations must be covered.

BACTERIOLOGICAL LABORATORY AND PROCEDURE

A laboratory was established by the New Jersey State Department of Health at Highlands, N. J., and all samples were examined the same day they were collected by personnel of that Department with a laboratory aide from the writer's station cooperating. Media and other supplies were brought from that Department's central laboratory in Trenton as needed. *Standard Methods of Water Analysis* were followed for the determination of *B. coli.* We did not plant 5 tubes of each dilution for each sample as is sometimes done in surveys of this kind. This procedure entails too much work for a field laboratory and we could have done it only at a sacrifice in volume of work. Hence, in the main, 1–10 c.c., 1–1 c.c. and 1–0.1 c.c. amounts were planted for each sample. As the interpretations were to be drawn on the basis of 1.0 c.c. tube results using those of the 10 c.c. and the 0.1 c.c. tubes as guides, this method was satisfactory.

Bacteriological Results and Their Interpretation

Chart II shows also for each sampling station the percentage of 1 c.c. tubes positive for *B. coli.* These are the critical values which are used to supplement the conclusions reached by an examination of all other information. In this case, high results were found in the far western end of the Bay and in that portion between Sandy Hook Point and Romer Shoal light and to the northwest of Sandy Hook Point. Except for isolated cases, the bacteriological results in the remainder of the Bay were quite satisfactory.

In recent years there has been considerable discussion among those engaged in sanitation activities related to shellfish as to what shall constitute a clean area for growing purposes. The Report of the Committee on the Sanitary Control of Shellfish in the United States in its supplementary report of 1927 treats this subject as follows:

> " As to what constitutes satisfactory evidence that an area is fully protected against contamination with disease-producing micro-organisms, judgment in any given case should be based upon all the facts available, considering different observations not separately but in their relation to each other. Thus, the correct interpretation of bacteriological examinations depends to a considerable extent upon what is shown by sanitary inspection and *vice versa.* Hence it would be unwise to attempt to set up any specific and inflexible standards of acceptability in terms of the findings on sanitary survey or bacteriological examination or both. It is our opinion, however, that on the basis of such examinations as have been outlined, areas may be classified generally as follows with respect to their fitness for the taking of shellfish for market:
>
> " (1) Areas from which the taking of shellfish should *not* be permitted.
>
> " (2) Areas which may be approved for the taking of shellfish without serious question. This class includes the areas which are so protected against human fecal contamination by distance from sources of such pollution, by dilution and by the time afforded for natural purification, that there is no discoverable likelihood of dangerous contamination.
>
> " (3) Areas which are intermediate between the first and second class as regards exposure to and protection against fecal pollution."

The Public Health Service after having done considerable work of this character has arrived at the conclusion that generally not more than 50 per cent of the 1 c.c. tubes in an area should show the presence of *B. coli* if that area is to be used for the taking of shellfish for the market. This is not an inflexible figure and can be used only as a guide when weighing all the evidence collected. This figure is in general use today for our field work and was applied in this specific survey.

On this basis the areas pointed out above were looked upon with suspicion and when considered in the light of the quantities of sewage coming into the waters at the mouth of Arthur Kill and through the Narrows; the movement of the tidal current back and forth across the mouth of the Narrows and the prevailing northwest winds, it was concluded to urge the closing of an additional area adjacent to Sandy Hook Point.

Results of Study

Chart I shows the areas in these waters which were officially closed by the New York and New Jersey State authorities before this survey commenced and the territory added to these as the result of this work. In 1925, all of the New York side of the Bay was closed and in 1934 a quarter mile strip along the New Jersey shore line. This work added to these condemned sections a triangular piece of water beginning at Sandy Hook Point and running along the channel leading to Seguine Point near Princess Bay in New York thence along the State boundary line which passes through Romer Shoal light.

After proper action by the New Jersey authorities this area was officially closed, whereupon the New York City Board of Health opened that city's markets to products from these waters with the provision that string clams be marked "For cooking purposes only."

Future of Area

The future of this area appears brighter. In New Jersey, Keansburg and Keyport (both immediately on the bay) have been ordered to improve their sewage treatment facilities and at Keyport a new plant is being constructed; action is progressing to further clean up the Shrewsbury River; wastes contributed to Arthur Kill by New Jersey communities will be measurably reduced by new plants for the Rahway and Elizabeth valleys, both of which are under construction; certain improvements in facilities in towns discharging to the Raritan River are under State and Court orders; and the operation of the new Perth Amboy plant has removed the menace of a large volume of raw sewage which was formerly discharged at a point extremely close to the shellfish beds. In New York, the new Coney Island plant will alleviate the situation at Sheepshead Bay where now 44 m.g.d. of raw sewage discharges directly east of the Bay; the Wards Island plant will remove about 280 m.g. from the East River daily; and the completion of the plans for treating the sewage from Staten Island in seven more plants will materially reduce the contributed load on the waters of the Upper Bay, Kill Van Kull and Arthur Kill.

Conclusion

Extension of the safe shellfish grounds in this Bay, therefore, await the installation of more sewage treatment works. A continuation of the present open area depends largely upon the efficient and unceasing operation of the plants in New Jersey located on Raritan Bay and its tributaries. Consequently, as in other cases, the life of this local industry is to a large degree dependent upon municipal authorities and sewage works operators. I trust that your efforts will all be towards making it possible for this industry to grow and flourish.

Editorial

REVIVAL OF THE TRICKLING FILTER

The trickling filter has always been a reliable, rugged device for the biological treatment of settled sewage, but during the past ten or fifteen years the activated sludge process and the recent furore over chemical treatment have almost relegated trickling filters to limbo. There were good reasons for this loss of prestige by filters, primarily the production of odors, plagues of *psychoda*, the requirement of large areas and high initial cost. The economy of operation of filters, even at the low rates that have been customary, has been their most attractive feature, and therefore filters are still being installed, in spite of the possibility of odors and flies and the production of an effluent somewhat inferior to an activated sludge effluent. A recent incentive toward the installation of filters has been the grant of 30 to 45 per cent available with PWA installations, thus reducing the first costs materially and favoring the selection of a process with high first costs but low operating costs.

For the past five years or more, various sewage experts have had the feeling that the rates of treatment customary with trickling filters have been far below the possible loadings, and research during the past few years is beginning to indicate that, with some modifications, filters may possibly be made to handle far greater loadings than have been used. This does not mean necessarily that the same high grade effluent can be obtained that has been obtained from filters operated at normal rates, and the practical outcome may be that filters will be used for a different function than the production of a completely treated effluent.

"Bio-flocculation" has been studied in various forms, such as Imhoff's tauchkorpers, Buswell's nidus racks, Doman's revolving discs, Maltby's biological wheel, Schimrigk's shavings, and other aerated surfaces, but until recently practically no consideration was given to the standard trickling filter as a basis for development of improved processes. In this conclusion, we must except the early work by Waring on trickling filters and Stroganoff's aerofilters. Waring's work was done long ago and Stroganoff has used such small filter media that the rates of filtration, as far as is known here, have not been very high.

The recent revival in the study of the trickling filter appears to originate from the work done for the past ten years by Dr. Max Levine at Ames, Iowa. Frederick G. Nelson, under the direction of Levine and Jenks, started work at Mason City, Iowa, on an experimental aerated filter 3½ ft. square and 10 ft. deep, treating settled wastes from the Decker packinghouse at the rate of 7 m.g.a.d. Later Jenks continued the work at the University of North Carolina (see THIS JOURNAL, May, 1936, p. 401). Levine has continued the work at Ames and his results will be published in our next issue. Dr. Halvorson, at Minneapolis, has for the past three years been investigating the dosing of experimental filters at very high rates, reaching 20 to 25 m.g.a.d.

Various investigators, including, recently, Jenks, Levine, Halvorson, Sperry and probably others, have re-circulated varying percentages of final effluent, and in Jenks' work the volume of effluent thus recirculated has been as great as 5 or more times the volume of discharged effluent. The use of artificial aeration has also been advocated, particularly by Halvorson when the temperature of the air and sewage are approximately the same. Levine has shown (THIS JOURNAL, May, 1934, p. 520) that, with milk wastes, complete prevention of bottom aeration resulted in very great deterioration of the effluent; when the bottom was again opened to the air, the effluent improved promptly.

For several years Drs. Blunk and Bach in Germany have been studying the possibility of aerating trickling filters artificially by means of heated air. Dr. Blunk proposes to enclose the filter and to re-circulate heated air. It is reported that the scheme has been installed at one or more towns in Germany but no operation data are as yet available. This scheme seems to be quite similar to the filter aerated with heated air (Ducat) referred to by Dr. Dunbar in 1912. Undoubtedly recirculation and aeration have been investigated in England, but no specific work comes to mind.

Another experimental study of trickling filter operation has been reported by Wiedeman and Singleton from Atlanta. They added small quantities of iron salts to the filter influent and reported that it was possible to operate the filter at considerably higher rates than a control filter not treated with iron salts. Enslow pointed out that Dunbar (*q.v.*, p. 399) had reported that it was observed that a contact filter containing iron nails had given better results than a similar filter with no nails; later experiments in 1899 with trickling filters confirmed this observation, and Dunbar speculated at length on the possibility of improving filter operation by use of iron. Filters of "Polarite" and of "Carboferrite" were used in England and Germany. Iron salts have also been investigated recently, in connection with biological filtration, by Rudolfs, Downes, and possibly others. In spite of all the work that has been done, the role of iron in biological filtration is still obscure and little practical advantage has accrued from the experimental work.

The present experimental work on the operation of filters at high rates is being carried on by Jenks in California, Levine at Ames, Halvorson at Minneapolis, and by the Sanitary District of Chicago at the West Side Treatment Works. All of these filters are of small size, none of them that have been operated exceeding 20 ft. in diameter. The need of larger scale work is of course apparent. The questions of odors, flies, freedom from surface clogging and costs of operation must be settled by large-scale tests, if possible. There is no doubt that the results to date give assurance that far greater removals of B.O.D. per acre-foot will be accomplished if the filter remains free from clogging. The Sanitary District filter has operated since September, 1935, at the rate of 20 m.g.a.d. of effluent without clogging. The use of revolving circular dosing equipment seems to have merit in providing uniform and continuous dosing, which is helpful in preventing fly nuisance and in obtaining maximum efficiency from the filter.

Probably the most important function of these high-rate filters is that of biological flocculation, and, for such purpose, they may prove to be lower in cost of operation than chemical flocculation. Secondary sedimentation is indispensable. Continuous unloading is also indispensable, as filters will quickly clog at such high rates unless stored solids are discharged freely and uniformly. For this reason, conclusions based on the operation, more or less continuous, of very small filters must be viewed with caution and if possible continuous experimental work for a year or more should be undertaken on the specific sewage that is to be treated. It is likely that no nitrification will be accomplished, for apparently the B.O.D. reduction remains in the first-stage carbon phase of oxidation, but this degree of treatment may undoubtedly be sufficient in many instances. At any rate, chemical flocculation now has a biological competitor, and the moribund trickling filter has a new lease on life.

F. W. M.

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION *

Eighth Spring Conference

Ontario, California, April 24–25, 1936

The Eighth Spring Conference of the California Sewage Works Association was featured by automobile caravan trips of inspection of the sewage disposal works of Pasadena, Whittier, Pomona, Ontario, San Bernardino, Redlands and Colton. One hundred and fifteen members of the association registered at the conference and almost the entire group joined in the trips of inspection held on the mornings of April 24 and 25.

Headquarters for the technical meeting were at Ontario. Following the trip on the morning of April 24, the group assembled for luncheon at the Hotel Ontario, listened to a word of welcome from Ontario's Mayor, George P. Weldon, and convened for a technical session lasting from two until five o'clock in the afternoon.

The association has long considered the advisability of voluntary licensing for sewage plant operators and the conduct of a short school to be held twice a year, serving the needs of those engaged in the practical problems of sewage treatment and disposal. Reports of committees engaged in these investigations were favorable to both, resolutions to that effect were unanimously adopted and at the annual meeting to be held in Santa Monica in September, concurrently with the convention of League of California Municipalities, a definite plan of procedure with respect to operator licensing and education will be adopted. Also at the September meeting it is expected that rules and regulations will be prescribed for protection of men engaged in the operation and maintenance of sanitary sewerage systems.

At the same meeting Whittier's city engineer, M. R. Bowen; F. C. Froehde, city engineer of Pomona; A. W. Wyman, plant superintendent of Pasadena, and Austin Burt, Ontario's city service manager, briefly described the interesting features at the disposal works of their respective cities.

The Friday afternoon session concluded with an address from Professor C. G. Hyde of the University of California, descriptive of the joint meeting of the New York State Sewage Works Association and the Sanitary Engineering Section of the American Society of Civil Engineers held in New York last January. Professor Hyde is a member of the Board of Control of the Federated Sewage Works Association of America.

George Hjelte, Superintendent of Playgrounds and Recreation for the City of Los Angeles, was guest speaker at a dinner meeting Friday

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* Minutes by courtesy of "Western City" for May, 1936.

evening. Mr. Hjelte is also vice-president of the American Shore and Beach Protection Association and spoke at length upon measures taken to protect the recreational facilities offered by Southern California beaches, touching upon the necessity for preventing shore pollution by sewage and other works of disposal. Palo Alto won the annual Association award for plant maintenance and operation.

Saturday morning, April 25, being devoted to a caravan of inspection of sewage disposal works, the conference reconvened in Ontario for a noon luncheon, listened to a description of the dehydration works installed at the Exchange Orange Products Company plant by the Combustion Engineering Company, and adopted in Chicago for the dehydration and incineration of raw sewage solids. William B. Senseman, West Coast representative for the company, presented the illustrated lecture. Mr. Senseman's discussion was followed by brief descriptions of the salient features of the San Bernardino, Redlands and Colton plants presented respectively by L. A. Hosegood, assistant water superintendent, San Bernardino, F. S. Currie for Redlands and A. B. Malloy, assistant engineer, San Bernardino, for Colton.

Mr. R. L. Patterson, city engineer of Newport Beach, briefly described conditions at Newport Beach with respect to salt water infiltration into the sewers and the elimination of odors from the sewers and the sewage disposal process.

H. E. Schlenz, vice-president of the Pacific Flush-Tank Company, Chicago, led a round-table discussion dealing with causes and cures for digester foaming, drawing upon his knowledge of conditions throughout the United States and Canada, and proposing definite rules which, if not followed, will contribute to this annoying phenomenon. Mr. Schlenz' remarks aroused a spirit of discussion and the subject was debated for nearly two hours from the floor. A great deal of information which will be helpful to sewage treatment works in California was contributed in this discussion.

The meeting was adjourned with notice to the members that the annual meeting will be held at Santa Monica September 14–15.

One hundred and fifteen members registered for the convention and at its close the secretary announced the paid-up membership in the California Sewage Works Association to be 190.

A. M. Rawn is president and F. D. Bowlus, secretary, of the Association.

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Spring Meeting

Hartford, Conn., April 27, 1936

The Spring Meeting of the New England Sewage Works Association was held April 27, 1936, at the Hotel Bond, Hartford, Connecticut. A total of 104 members and guests registered for the various sessions.

The business meeting was called to order by President Griffin at 10:30 A.M. The secretary presented a report of the joint meeting with the New York State Sewage Association in Schenectady. The reports of the treasurer and secretary were also read and accepted.

President Griffin announced the appointment of two additional members on the Membership Committee, namely, Mr. Leonard Traeger, of Concord, New Hampshire, and Professor E. H. Sprague, of Orono, Maine.

President Griffin stated that the Executive Committee had considered plans for the next annual meeting of the association and would like an expression of opinion from the association regarding the desirability of making this a two-day meeting instead of the usual one day. After some discussion from the floor, it was voted to instruct the Executive Committee to proceed with the plans for the annual meeting on the basis of a two-day period. The business session was adjourned to permit the presentation of the papers on the morning program.

The first paper, "Safety Methods in Sewage Treatment Plants," was presented by Mr. E. Sherman Chase, chairman of a joint committee with the New York Association on Safety in Sewage Treatment. The second paper on the morning program was presented by Mr. C. C. Agar, of Albany, New York, "Observations on the Operation of Sewage Treatment Plants." The third paper consisted of a symposium on "Operating Experiences during the Recent Floods." Messrs. R. S. Lanphear, W. E. Merrill, W. J. Shea, H. E. Holmes, F. A. Nicoli, and C. I. Sterling gave very interesting accounts of the flood conditions that came under their observation, and the methods used in the operation of sewage treatment plants under these very unusual and trying circumstances.

The morning session adjourned at 1:00 P.M. for luncheon in the English room of the Hotel Bond.

Following luncheon, Mr. John H. MacKey, President of the Board of Aldermen of the City of Hartford, welcomed the association to the city. Also Mr. Charles D. Goodwin, Chairman of the Hartford Metropolitan District Commission, spoke to the members and their guests, expressing his regrets that the recent flood rendered an inspection of the Hartford Sewage Treatment Plant impossible.

Following the luncheon, Mr. Leroy W. Van Kleeck presided at the round-table discussion and question-box period. The discussion centered around the problem of safety methods and covered in particular gas hazards and the use of non-sparking tools in sewage treatment plants. Several of these tools were displayed and their use and value explained.

Following adjourment of the round table period, the members and guests boarded buses furnished through the courtesy of the Guggenheim Bros. for an inspection trip of the New Britain "Pilot" plant. At the plant, guides conducted small parties through the plant, explaining in detail the process and the experimental work.

Leaving the New Britain plant, the buses proceeded to the Cedarcrest Sanatorium Sewage Treatment Plant in Newington, Connecticut. This plant is of especial interest because of the large volume of laundry waste which is treated separately, and the effluent discharged with that for the sewage treatment process. The buses then returned to the Hotel Bond, and the members and guests assembled for dinner at 6:00 P.M.

Following dinner, President Griffin introduced Mr. Roscoe Clark, City Engineer of Hartford, who spoke briefly. The guest speaker for the evening was Dr. Stanley H. Osborn, Commissioner of Health for the State of Connecticut, who gave a most interesting address, "Teaming up for Public Health."

F. W. GILCREAS, *Secretary-Treasurer*

MARYLAND-DELAWARE WATER AND SEWERAGE ASSOCIATION

Tenth Annual Conference

Frederick, Maryland, May 14 and 15, 1936

Considerable interest and enthusiasm made the Tenth Annual Conference of The Maryland-Delaware Water and Sewerage Association one of the most successful meetings in the history of this organization. The meeting which was held in Frederick, Maryland, on May 14 and 15, was well attended, there being a total registration of 132, with 116 attending the annual banquet on the evening of the first day.

After the address of welcome by the Mayor of Frederick, the morning session and most of the afternoon was devoted to papers on water treatment. These were followed by several papers on sewage treatment.

"Combined Collection and Disposal of Garbage and Rubbish" was the subject presented by Morris M. Cohn, Editor of "Municipal Sanitation." Mr. Cohn suggests two methods which may be used to combine these two sanitary functions into one: first, the collection of garbage in the usual manner and transporting it to municipal grinding stations located at convenient points along the route of main sewers, grinding this mass of waste and discharging it into the sewers; second, the installation of grinders at the kitchen sinks of individual homes, where the material after grinding can be flushed into the sewer. Mr. R. C. Beckett, State Sanitary Engineer, led the discussion of this paper and a lively debate was carried on both for and against this combined collection and treatment of garbage.

The first paper of the second day was presented by Dr. Willem Rudolfs, Chief, Division of Water and Sewer Research, New Jersey Agricultural Experiment Station. Dr. Rudolfs' subject was "Trends in Sewage Treatment" and this very excellent paper was ended with the following conclusions: (1) Modern chemical treatment will be perfected and continue to be one of the important methods of sewage treatment without replacing other methods; (2) Physical treatment processes will make great strides, without displacing chemical or biological methods; (3) Biological treatment processes will be improved and again come to the front, finding its own place; (4) Each method will fit the peculiar needs of the locality. Stimulation and perfection of all three methods is, therefore, desirable and necessary to provide greater choice and more possibilities to serve the needs; (5) With this increase in types of treatment, sewage purification and stabilization will increase; (6) Future sewage treatment will be, in general, more costly, but lower in cost for equal purification than obtained by present methods; (7) With increased complexity of methods of treatment, operation difficulties will decrease, control will be more exact, and more uniform results will be obtained, and (8) Future sewage treatment plants will call for better and more extensively trained operators, but will require less manual labor.

The final paper on "Frederick's Water and Sewerage System" was given by Elmer St. C. Maxwell, City Engineer, Frederick, Md. This paper, describing the development of the sources of water supply and the plans for the sewerage system and treatment plant now under construction, was discussed by Mr. G. J. Requardt, Consulting Engineer.

At the business meeting Mr. James V. Cannen, Chief Chemist, Hagerstown Water Filtration Plant, was elected President, succeeding Mr. L. D. Shank, City Manager of Dover, Delaware. Mr. Edward S. Hopkins, Principal Sanitary Chemist, Baltimore City Water Department, was elected First Vice-President and Mr. C. J. Bruce, Superintendent, Evitts Creek Water Company, was elected Second Vice-President. A. W. Blohm, Assistant Sanitary Engineer, Maryland State Department of Health, was re-elected Secretary-Treasurer. Mr. W. Compton Wills, Chief Engineer, Wilmington, Delaware, Water Department, was elected to the Executive Committee for a 4 year term. The constitution of the Association was revised to include active members from the District of Columbia, and non-resident membership was provided for engineers and operators outside of the area covered by the Association, namely Maryland, Delaware and the District of Columbia. Rehobeth Beach, Delaware, was tentatively selected for the 1937 Conference.

Sightseeing trips were provided for the ladies, and the inspection trips were to the Frederick water and sewer projects.

A. W. Blohm, *Secretary-Treasurer*

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Spring Meeting

Lido Beach, Long Island, June 11–13, 1936

The New York State Sewage Works Association held its Spring Meeting at the Lido Club Hotel, Lido Beach, Long Island, June 11, 12 and 13. Two hundred and sixty members and guests, including fifty ladies, were registered. Exhibits of twenty-seven manufacturers were instructively displayed in very attractive booths. All of the splendid recreational facilities of this unique club hotel were thrown open to those attending the convention.

The convention opened with registration and inspection of manufacturers' exhibits Thursday noon, with an informal supper dance in the evening.

On Friday morning following the registration period the Convention was welcomed by Lester B. Sprague, General Manager of the Lido Club. This was followed by a general business meeting of the Association, and a brief business meeting of the Long Island Section. The Secretary of the parent body reported that there were 441 members in the Association, including the new members just received. Three technical papers were presented during the morning session. Clarence MacCallum, Consulting Engineer, Nassau County Sanitation Commission, spoke most interestingly and clearly on the sewage disposal program for Nassau County. Professor Charles L. Walker of Cornell University gave a progress report on the experiments with activated carbon at the Ithaca sewage treatment plant. H. P. C. Howe, District Director, Works Progress Administration on Long Island, gave a brief talk on "Buying Community Sanitation at Reduced Costs Through W.P.A. Projects," which was illustrated with moving pictures of actual construction work.

At the luncheon A. F. Dappert, Chairman of the Rating Committee, presented an engraved silver loving cup to C. George Andersen in recognition of the high rating attained by his report on the operation of the Rockville Centre sewage treatment plant for the year 1935. Chairman C. A. Emerson of the Federation of Sewage Works Associations expressed his gratification at the establishment of this Rating Award, and indicated his hope that in a few years it would become a nation wide affair.

Allan Johnstone as Prof. Hans Morgenichten von Ziffleblatt presented a most enjoyable comedy skit illustrated with lantern slides, setting forth some of his theories and a new method of sewage treatment.

The afternoon was devoted to recreation including a personally conducted trip to Jones Beach, and a review of water sports events especially arranged for the group by the Long Island State Park Commission.

Friday morning the ladies enjoyed a picturesque bus trip across the island to Theodore Roosevelt's grave at Oyster Bay, and after luncheon at the club house in the beautiful Bethpage State Park, joined the men at Jones Beach.

At the banquet Friday evening the Honorable Lithgow Osborne, State Commissioner of Conservation, was the guest speaker, and used as his topic "Conservation of our Water Resources." This admirable talk was most enthusiastically received. The banquet was followed by entertainment in the form of a floor show and dancing until well after midnight.

Saturday morning following the sunrise breakfast a lively question box and round-table discussion was conducted by Charles C. Agar, Vice-President of the Association. This was followed by a brief talk by Seth Hess, Assistant Engineer of Inspection of the Public Works Administration, after which Mr. C. George Andersen presented a paper on "Methods for Operating the Activated Sludge Plant at Rockville Centre, and Prevention of Bulking." Albert C. Rogel of New York University presented a paper on the "Disposal of Garbage in Sewers" which gave the results of some research work carried on recently at the University under the direction of Prof. L. V. Carpenter. A Symposium on Sludge Utilization followed, and many interesting points were brought out.

Although the meeting adjourned at noon many of those attending stayed on to enjoy the recreational features of the Lido Club Hotel.

The next meeting of the Association will be at Geneva, N. Y., October 9 and 10, 1936.

The following had exhibits at the meeting—

Eimer and Amend, New York, N. Y.
The American Brass Co., Waterbury, Conn.
The Carborundum Co., Niagara Falls, N. Y.
Long Island State Park Commission (Display of a large topographical relief map of Long Island; also Bethpage State Park)
Norton Company, Worcester, Mass.
Electro Bleaching Gas Company, New York, N. Y.
Wailes, Dove-Hermiston Corp., New York, N. Y.
Chicago Pump Company, Chicago, Ill.
Municipal Sanitary Service Corp., New York, N. Y.
Proportioneers, Inc., Providence, R. I.
Inertol Company, Inc., New York, N. Y.
Mine Safety Appliances Co., Pittsburgh, Pa.
W. & L. E. Gurley, Troy, N. Y.
Link-Belt Company, Philadelphia, Pa.
L. A. Weston, Adams, Mass.
Quigley Company, Inc., New York, N. Y.
C. G. Wigley, Atlantic, N. J.
Wallace & Tiernan Co., Newark, N. J.
Lord & Burnham Co., Irvington, N. Y.
Pittsburgh Equitable Meter Co., New York, N. Y.
Atlantic Cement Products, Inc., Hicksville, N. Y.
Portland Cement Association, New York, N. Y.
Ralph B. Carter Co., New York, N. Y.
Multiplex Concrete Co., Inc., East Orange, N. J.
The Robinson Clay Prod. Co., New York, N. Y.
Lock Joint Pipe Company, Ampere, N. J.
Industrial Chemical Sales Co., New York, N. Y.

ARTHUR S. BEDELL, *Secretary-Treasurer*

Operators' Reports and Suggestions

W. D. HATFIELD

SAN BERNARDINO DISPOSAL PLANT *

BY L. A. HOSEGOOD

Engr. and Ass't Supt., San Bernardino Water Dept.

In the operation of a sewage treatment plant there are many interesting problems. In San Bernardino we are vitally interested in three, —First: The sterilization of the effluent from the plant, Second: Obtaining a thoroughly digested sludge capable of being used for fertilizer, and Third: The control of odors. Our greatest difficulty has been the elimination of odors, particularly while keeping in mind our interest in economy of operation. Due to the topography and other controlling features, the San Bernardino Plant was located one mile south of the city, which made a gravity system possible. As the prevailing winds are from the southwest, odors from the plant are carried across the state highway which runs parallel to the plant 700 feet to the east and to the territory directly south of the city.

To avoid an odor nuisance odorous gases must be nullified, particularly hydrogen sulphide which is not only very offensive to the olfactory organs but easily conveyed by air currents over the surrounding territory. We are endeavoring to remedy this condition by delaying or preventing the formation of odors before the sewage reaches the plant, and by confining the odors that originate at the plant by the installation of gas collectors on the Imhoff tanks, and deodorizing these gases by incineration.

We are at the present time using liquid chlorine as the sterilizing agent, which is applied in varying quantities at different phases of the treatment. At the Orange Show building the sewage enters an inverted siphon 6400 feet long, through which the sewage takes approximately one hour to reach the plant. It is at this point that the first treatment takes place. Equipment has been installed to handle 1-ton containers of liquid chlorine with a 300 lb. Wallace and Tiernan machine. The amount of chlorine applied varies from time to time and is adjusted so that a reading of 1.0 part per million is the maximum amount of hydrogen sulphide present at the stack where the sewage enters the plant, at the time of maximum flow. The change in the settings are made twice per day, 7 a.m. and 7 p.m. During the period of low flow, residual chlorine will be present, approximately 0.5 p.p.m. This arrangement has proven quite successful.

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* Presented before the Eighth Spring Conference of the California Sewage Works Association, Ontario, Cal., Apr. 24, 1936.

The gases from the Imhoff tanks are confined by sealing the gas vent areas and installing gas domes. The gas is either conveyed to burners or to two 750 cu. ft. lift-type gas holders, to be used for the operation of an electric generator which is direct connected to a 40-horse power, 4-cylinder gas engine. This piece of equipment is used only for emergency purposes.

The greatest odor nuisance originates from the trickling filters while they are in operation. In order to combat this, the effluent is chlorinated at both dosing chambers. Chlorination at this point reduces the H_2S and also prevents the growth of algae on the beds. The amount of chlorine used depends to a large extent upon the expense involved. At the present time we are able to keep the H_2S readings down to 0.5 p.p.m. and under. During the summer with the increase in temperatures we endeavor to prevent the H_2S from exceeding 1.0 to 1.5 p.p.m. At this point we notice a slight odor at the plant but it is usually dissipated by the time it reaches the state highway. With the use of additional chlorine we would be able to reduce the H_2S but it is not economical to do so as long as the odors do not reach the highway or the nearby residences.

The other application of chlorine is entirely for sterilization purposes. The effluent from the plant is chlorinated to a residual chlorine reading of 1.0 to 1.5 p.p.m. The effluent is discharged into Warm Creek, to be later used for irrigation.

We have a normal domestic sewage in San Bernardino due to the absence of canneries and other industrial waste, so no great difficulty has been encountered in the operation of the plant.

In December we made an interesting study of the use of ozone as a sterilizing agent at the plant. It was rather unfortunate that these tests were made during the time when the hydrogen sulphide readings were very low and in addition a series of mechanical difficulties interrupted the tests, so no definite conclusions were reached. Hydrogen sulphide was determined by the antimony potassium tartrate method. From neutrality to 1.0 p.p.m. there is such a slight difference in color that it was difficult to arrive at any definite conclusions as to the reduction in the hydrogen sulphide. It was contended by the Min-O-Zone people that there was a reduction in bacteria from the raw sewage to that ozonized. We were not satisfied, however, by the results obtained by the hydrogen sulphide readings.

The San Bernardino Plant was designed and constructed under the supervision of the Currie Engineering Company in 1929. It was operated under the direction of the city engineer until May, 1935, at which time it was placed under the management of the superintendent of the municipal water department. Since we have taken charge, we have experimented more or less with different chlorine applications to obtain the most efficient operation. The cost figures that I have compiled therefore will cover the entire eleven months that we have operated the plant, as this will give a more comprehensive statement than one compiled by months.

The following statement shows the money spent under each heading and reduced to cost per million gallons treated, the average daily flow being 2,941,500 gallons.

Item	Total Cost	Cost Per M. Gal.
Wages	$ 5,340.00	$ 5.40
Light and power	232.20	.23
Equipment and tool repairs	578.24	.59
Telephone	32.60	.03
Liquid chlorine	3,351.17	3.39
Capital repairs	1,263.17	1.28
Other maintenance	1,214.92	1.23
Total	$12,012.30	$12.15
Total revenue	1,640.50	
Net Operating Cost	$10,371.80	$10.49

The revenue was from the sale of 19,300 cu. ft. of sludge for fertilizer at 8½ cents per cu. ft. The greatest expense in the plant operation was for labor which amounted to 44.5 per cent. This was for three full-time employees, who arrange their shifts so that there is an operator on duty from 7 a.m. until 7 p.m. daily and a night watchman who is on duty the other twelve hours.

Chlorine amounted to 27.9 per cent of the total cost. During the eleven-month period there was an average use of 285 lb. of chlorine daily or at a rate of 11.6 p.p.m. Of this amount, prechlorination at the Orange Show building received 5.3 p.p.m.—dosing chambers 4.0 p.p.m. and the final tank 2.3 p.p.m.

We are not entirely satisfied with the results that we have obtained so far and expect to make additional changes in the future to obtain the most efficient operation at the least cost.

FURTHER COMMENTS ON GAS ENGINE OPERATION AT LOS ANGELES *

By Carl F. Tennant

Chief Operator, Los Angeles County Sanitation Districts Disposal Plant

The engine placed in service May 4, 1935, by the Los Angeles County Sanitation Districts and described before this Association last fall at San Francisco has given complete satisfaction and has justified the most optimistic expectations. (See This Journal, Jan., 1936, p. 64.)

On April 1, 1936, a total of 1,373,809 h.p. hours had been developed, having a gross power value of $7,281.19 when compared with electric energy at 65c per K.W.H. Operation and maintenance charges such as oil, spare parts, operators' time and payments on the maintenance contract amount to $1,013.15. Capital charges amount to $962.50. This shows a net operating profit returned to the Districts in the form of power saving of $5,305.54 in the first 11 months of service.

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* Presented before the Eighth Spring Conference of the California Sewage Works Association, Ontario, Cal., Apr. 24, 1936.

The oil consumption has increased slightly above the figure reported last fall. At present 1 gallon of oil is used for each 4250 h.p. hours developed. This increase in oil consumption is due in part to increased power output, there being more of the time that the engine operates at high speed than when formerly reported. This unit is operating 24 hours per day and is developing 91 per cent of the maximum power output. (In March, a rainy month, the load factor was 94.5 per cent.) The latter part of July, 1936, after less than 15 months of service, this unit will have returned the entire cost plus all operation and maintenance charges, interest and depreciation.

During the eleven months the engine has been in use it has been out of service 7/10 of 1 per cent of the time, or approximately 5 hours per month. The oil has not been drained for nine months. It is analyzed regularly every two weeks in the laboratory of the Union Oil Co. and continues to be reported as satisfactory for further service.

After eleven months of continuous service the engine is in good mechanical condition and will without doubt give many years of faithful service.

FIFTH ANNUAL REPORT (1935) SEWAGE TREATMENT PLANT, AURORA SANITARY DISTRICT, AURORA, ILL.

By W. A. Sperry

Superintendent

It has been necessary to cut this rather complete and delightful report to the essential tables of data, therefore this short review does not do justice to the full report. It is hoped, however, that the data presented in this condensed review give a clear picture of operation of the plant and the quality of the effluent produced (W. D. H.).

Table No. 1 presents the operating cost for the Treatment Plant and Interceptor System. Such items as interest, bond payments, insurance premiums, attorney and engineers fees and other over-head administrative expenses are not dealt with in this report. All credits

Table 1.—*Showing Distribution of Plant Operating Costs for the year 1935*

Mo.	Payrolls	Power	Truck	Phone	Office	Lab.	New Equip.	Repairs	Misc.	Total
Jan.	$1,855.71	$606.42	$12.47	$9.20	$21.51	$40.99		$302.10	$93.65	$2,942.05
Feb.	1,420.91	611.41	3.91	10.20	52.70	7.24	$8.12	46.12	64.47	2,225.08
March	1,064.35	647.15	1.66	11.40	27.81	1.85		93.85	75.81	1,923.88
April	1,325.66	672.05	2.42	9.50	.94	46.88	19.40	26.38	144.28	2,247.51
May	1,458.09	664.04	4.37	9.00		.80	5.86	177.54	61.82	2,381.52
June	1,412.68	612.65	5.56	11.80	13.90	6.92	5.28	73.20	107.72	2,249.71
July	1,675.40	588.93	4.58	13.85	15.64	4.35		34.95	209.96	2,547.66
Aug.	1,412.38	668.97	7.02	9.70	37.39	24.50	85.56	39.30	61.07	2,345.89
Sept.	1,417.71	655.83	2.40	11.25	25.58	1.24	560.67	33.91	45.71	2,754.30
Oct.	1,569.19	676.50	7.27	10.72	35.40		285.98	44.56	71.65	2,701.27
Nov.	1,293.66	677.54	1.65	9.35	1.39	21.57	55.56	21.52	11.35	2,093.59
Dec.	1,305.41	693.42	3.48	9.00	25.82	1.00	19.64	16.24	30.64	2,104.65
Totals	$17,211.15	$7,774.91	$56.79	$124.97	$258.08	$157.34	$1,046.07	$909.67	$978.13	$28,517.11

TABLE 3.—*Tabulation Showing the Quantity and Type of Materials Removed from the Sewage Treated in 1935*

	Sewage Treated *Mil. Gals.*	Total Rainfall *Inches*	Screenings *Cu. Ft.*	Grit *Cu. Ft.*	Grease and Scum *Cu. Ft.*	Equiv. Dry Solids to Digs. *Tons*	Susp. Solids Removed by Filts. *Tons*	Gas Produced *Cu. Feet*	Dried Sludge to Storage *Cu. Yds.*	Total Ox. Dmd. Raw Sewage *Tons*	Total Ox. Dmd. Effl't Sewage *Tons*	% Red.	Total Ox. Av. Lb. in Fox River *Tons*
Jan.	206.54	2.20	319	484	91	52.63	26.0	1,008,600	446	116	31	73.2	854
Feb.	180.76	1.46	328	455	84	55.95	19.0	969,900	—	104	25	76.0	589
Mar.	258.50	3.26	361	935	66	47.10	39.0	765,400	—	88	24	72.8	3038
Apr.	229.56	2.12	351	645	42	39.00	30.5	655,200	—	89	22	75.4	1195
May	223.50	5.16	295	705	81	89.41	—	1,009,500	356	103	24	76.7	711
June	184.95	3.89	355	662	66	86.22	1.5	1,130,900	—	92	21	77.2	324
July	208.22	3.76	309	736	63	78.31	30.2	1,197,600	469	103	18	82.5	365
Aug.	235.13	7.58	309	591	63	69.27	32.0	970,200	—	85	14	83.5	253
Sept.	222.42	4.18	343	463	52	65.30	31.5	923,400	—	87	12	86.2	223
Oct.	194.70	2.11	381	412	50	75.34	33.0	1,202,000	602	97	15	84.6	220
Nov.	248.78	4.23	377	895	45	45.19	37.2	522,300	—	63	15	76.3	741
Dec.	239.90	1.09	459	665	66	66.97	25.0	1,257,900	—	97	36	63.0	611
Total	2632.96	41.04	4187	7648	769	770.69	304.9	11,612,900	1873	1124	257		9124
Filters in Use 353 Days													
Mo. Ave.	219.4	3.43	349	637	64	64.22	25.41	967,740	—	93.6	21.4	77.0	760
Dl. Ave.	7.213		11.2	20.95	2.11	2.11	.83	31,820	—	3.08	0.7		25.0
1 M.G.			1.55	2.91	0.29	0.29	.115	4,415	—	0.43	0.09		3.4
Averages for 1934: Total	2042.3	26.93	2890	4682	961	744.25	191.2	13,264,600	1550	1161	474		3199
Filters in Use 239 Days													
Mo. Ave.	170.2	2.24	241	390	80	62.02	23.9	1,105,380	—	96.8	39.5	59.4	266.6
Dl. Ave.	5.596		7.9	12.83	2.63	2.04	0.8	36,340	—	3.18	1.29		8.75
1 M.G.			1.41	2.29	0.45	.36	.14	6,500	—	0.57	0.23		1.56
Averages for 1933: Total	2403.1	30.45	3096	5775	926	639.11	153.9	10,324,200	1348	1192.1	593		9771
Filters in Use 156 Days													
Mo. Ave.	200.26	2.53	258	481	77	53.25	25.67	860,350	—	99.3	49.4	50.2	814.2
Dl. Ave.	6.58		8.5	15.8	2.54	1.75	.99	28,286	—	3.27	1.63		26.8
1 M.G.			1.28	2.4	0.34	0.266	.164	4,280	—	0.495	0.247		4.1

directly to the Plant, as funds received from insurance compensation, are accounted for so that the cost reported herein is net.

The cost per million gallons treated is 21.3 per cent less than for 1934. The flow, however, was 29.0 per cent more than for 1934. This reduced the unit cost. So far as it is possible to estimate, the plant still served approximately 47,000 persons in 1935, so that the cost per capita was 6.2 per cent more than in 1934.

The principal reason for increases of total cost is found in an increased current bill of approximately $2500.00 or 48.0 per cent more than for 1934. The filters in 1935 were operated for 353 days as against 239 days in 1934. The costs are further increased by reason of an expenditure of about $900.00 for the installation of an additional sludge pump.

Table No. 3 has been reserved for the tabulation, in one place, of all the major quantities and types of material handled throughout the year. Comparative conditions for the years 1933, 1934 and 1935 are indicated. It will be noted that this tabulation reflects throughout, the key fact, that rainfall in 1935 was 52.4 per cent more than that of 1934 with total inches of 41.04 versus 26.93. The dry weather flow per capita, calculated to 98 gallons in 1934 and 91 gallons in 1933 is estimated to be 138 gallons in 1935 taken from two months with an average rainfall of 1.8 inches and with a daily flow of 6.5 million gallons, and at a time when ground water influence was at a minimum. They reflect, however, an enormous amount of dilution from ground water throughout the year. The annual average volume treated per capita for the year was 149 gallons in 1935, 119 gallons in 1934 and 141 gallons in 1933.

As against three general sludge bed cleanings in 1934 four were required in 1935 at a cost of $933.00 as against $569.00 in 1934. The cost per yard of sludge removed increased from 37 cents in 1934 to 50 cents in 1935 due to the difficulty of winter cleaning where the cost approached 83 cents per cubic yard.

Table No. 4 contains the average gas analyses during 1933–34–35. There is very little variation in the gas analyses from month to month. Therefore the monthly data have not been copied.

Gas production in 1935 was 12.4 per cent less than in 1934. Cubic feet per capita was 0.678 as against 0.772 in 1934, a reduction of 12.1 per cent. The pounds of equivalent dry solids to the digestors was 3.6 per cent less than in 1934. The volatile matter of solids to the digestors dropped from 72.1 per cent to 67.0 per cent in 1935.

The following table compares gas per ton of material, volatile matter and cubic feet of gas per pound of volatile matter added.

	Cu. Ft. Gas per Ton of Sludge	% Vol. Matter	Cu. Ft. Gas per Lb. of Vol. Matter Added
1932	17,000	67.5	12.9
1933	16,400	67.0	13.1
1934	17,800	72.1	12.9
1935	15,100	67.0	11.4

TABLE 4.—*Gas Analyses and Volume*

	Composition of Gas									Gas Produced, Total
	CO_2	O	H	CH_4	N	B.T.U.		H_2S		
						Gross	St. Cond.*	P.P.M.	Grs. 100 C.F.	
Aver. 1935	32.3	0.6	3.5	61.2	2.3	629	594	543	28.7 Yr. Mo. Day T° F.	 11,612,900 967,740 31,820 84
Aver. 1934	31.9	0.4	2.1	63.0	2.6	643	606	410	21.5 Yr. Mo. Day T° F.	 13,264,600 1,105,380 36,340 87–94
Aver. 1933	31.1	0.6	5.1	60.6	2.6	628	594	415	21.9 Yr. Mo. Day T° F.	 10,324,200 860,340 28,280 84

* B.T.U. (Standard conditions = 30 inches).

On the basis of 65 lb. per 1,000 cubic feet, the 11,612,900 cubic feet of gas produced in 1935 represents a total mass of 377.4 tons, or at the rate of 1.03 tons per day with a calculated specific gravity of 0.85.

The distribution of the gas used in 1935 is shown in the following table.

	Annual Cu. Ft.	Aver. Daily Cu. Ft.	Per Cent Distribution	
			1935	1934
Gas used for heating digestors, building and laboratory	7,788,200	21,340	67.1	59.3
Gas used in the incinerator	2,450,100	6,710	21.1	22.6
Gas wasted	1,374,600	3,770	11.8	18.1
Total	11,612,900	31,820	100.0	100.0

In December arrangements were completed and contracts signed for the installation of two 70 horsepower sewer-gas-driven engines, direct connected to each of the 8 million gallon pumps serving the dosing chambers of the filters. These engines are being installed under the P.W.A. grant plan. The contract price was $12,235.00. The government grant was 45 per cent of this amount.

Aurora, Ill.—*Average Daily Operation Data*

1936	Rainfall	Sewage Flow M.G.D.	K.W.H./M.G.D.	Screenings Cu. Ft.	Grit Cu. Ft.	Clarif. Skin Cu. Ft.	Sludge Data			T° F. Digestors	Gas Total Cu. Ft.	Chemical Analysis P.p.m.							
												Raw		Settled		Filtered			
							% Solids	% V.M.	Total Lbs. Solids to Dig.			B.O.D.	S.S.	B.O.D.	S.S.	B.O.D.	S.S.	NO_3–N	Day Stable
Jan.	2.20	6.66	158	10.3	15.6	2.9	3.8	77.4	3390	86	32,530	135	157	97	63	36	23	5.6	17
Feb.	1.46	6.46	163	11.7	16.3	3.0	4.3	72.5	4000	85	34,640	139	167	101	63	33	38	4.1	20
Mar.	3.26	8.34	159	11.7	30.2	2.1	3.9	63.3	3040	81	24,690	82	123	58	56	22	21	4.2	19
Apr.	2.12	7.65	158	11.7	21.5	1.4	2.8	70.8	2600	73	21,840	94	161	61	72	23	40	4.1	19
May	5.16	7.21	161	9.5	22.7	2.6	6.5	62.3	5770	80	32,550	111	162	75	78	26	78	4.9	18
June	3.89	6.17	164	11.8	22.1	2.2	6.4	61.3	5740	81	37,700	120	158	81	62	28	60	5.5	16
July	3.76	6.71	163	10.0	23.7	2.0	6.3	63.6	5050	90	38,630	119	159	90	62	21	27	4.9	19
Aug.	7.58	7.59	157	10.0	19.1	2.0	6.0	54.4	4470	95	31,300	87	145	56	54	14	21	5.5	19
Sept.	4.18	7.41	159	11.4	15.4	1.7	4.6	65.4	4350	88	30,780	94	157	64	59	13	25	4.4	19
Oct.	2.11	6.28	166	12.3	13.3	1.6	4.5	73.2	4860	89	38,770	120	163	78	67	19	26	5.6	18
Nov.	4.23	8.29	161	12.9	29.8	1.5	2.7	66.2	3015	79	17,410	61	105	42	55	15	19	7.0	17
Dec.	1.09	7.74	118	14.8	21.7	2.1	3.6	76.4	4320	88	40,570	97	123	74	67	15	24	6.2	13
Average	3.43	7.21	157	11.2	20.9	2.6	4.6	67.0	4220	84	31,820	105	148	71	63	22	34	5.1	18

Table 5 showing the individual operation of the digestors is not shown in this summary but Table 6 gives a good summary of the composite operation of the digestors. Tables 7 and 8 (not included in this summary) give monthly data on the bacterial removal of the plant and the bacterial density in the Fox River above and below the plant, and Table 9 gives the chemical data on the Fox River.

Table 10 is a condensation (by the editor) of the annual operation record given at the end of the report.

TABLE 6.—*Showing Composite Operation of the Digestors for the Year 1935*

	Total Solids, lbs.	Volatile Matter, lbs.
In tanks 12/28/34	294,793	143,150
Added in January	113,540	84,400
Added in February	112,610	80,770
Added in March	101,290	66,875
Added in April	75,555	53,517
Added in May & June	343,360	219,300
Added in July	155,390	98,765
Added in August	128,150	70,555
Added in Sept.	138,590	91,647
Added in October	146,859	106,412
Added in November	90,790	59,340
Added in December	128,930	96,493
Total	1,829,957	1,171,324
In tanks 12/27/35	200,227	98,588
Remaining in tanks	1,629,730	1,072,736
To beds in 1935 *	897,849	400,043
Reduction in 12 months	731,881	672,693
Aver. reduction per month	60,990	56,058
Aver. input per month	127,930	85,681

Average results for:	1935	1934	1933
Aver. % reduction in Total Solids	47.7	41.5	52.9
Aver. % reduction in Volatile Matter	65.4	60.5	68.5
Average Temperature—Fahr. degrees	85	89	84
Aver. % Solids in Raw Sludge	4.5	5.3	5.5
Aver. % Volatile Matter in Raw Sludge	67.8	71.4	68.2
Aver. % Solids in Digestors	7.0	6.6	8.9
Aver. % Volatile Matter in Digestors	45.5	48.2	43.4
Aver. % Solids at the bottom layers	9.3	8.5	13.2
Cubic feet gas:			
(*a*) per pound of vol. matter added	11.4	12.8	13.1
(*b*) per pound of vol. matter destroyed	17.2	21.0	19.1
Based upon gas produced:			
(*a*) % reduction in Total Solids	49.5	59.0	54.5
(*b*) % reduction in Vol. Matter	81.8	83.2	82.5
Based upon the change in ash content:			
(*a*) % reduction in Total Solids	40.1	44.3	43.7
(*b*) % reduction in Vol. Matter	60.3	86.2	77.5

* Solids discharged to beds in March, June, September and November, 1935.

ANNUAL OPERATION REPORT FOR 1935, SANITARY DISTRICT OF SPRINGFIELD, ILLINOIS

By C. C. Larson

Chemist in Charge

This rather unique report contains a one-page summary of the history of the Springfield District, a one-page engineering description of the treatment plant, a map of the District, 24 pages of tabular data covering the complete operation of the plant, and a one-page description and picture of the new gas engine installation which is connected both to a blower and to a generator. This is the second gas engine installation at Springfield. Omitted from this condensation are detailed tables and graphs the essence of which is to be found in the Summary Table or the other tables. (W. D. H.)

Table I.—*Statistical Summary*

Yearly Totals	1931	1932	1933	1934	1935
Connected population	70,000	70,000	70,000	70,000	72,000
Population equivalent	67,975	74,268	66,700	72,525	62,104
Sewage treated—in million gals.	2,308	2,811	2,396	2,303	2,471
Air consumed—in million cu. ft.	1,424	2,445	1,922	2,133	1,850
Solids added to digestors—in lbs.	2,246,300	3,267,300	2,766,000	3,501,500	3,103,518
Volatile solids added to digestors	1,398,340	1,999,300	1,778,000	2,255,400	1,929,121
Dry sludge produced—in tons (50 % moisture)	1,025	1,475	1,178	770	959
Gas produced—in cubic feet	14,860,000	13,790,148	14,817,905	19,655,615	18,735,057
Miscellaneous Factors					
Gas in cubic feet per capita per day	.58	.54	.58	.77	.71
Gas in cubic feet per pound of solids added to digestors	6.62	4.22	5.36	5.61	6.04
Gas in cu. ft. per pound of volatile solids added to digestors	10.62	6.90	8.23	8.72	9.71
Per cent reduction of suspended solids in digestors	42.5	26.6	38.7	32.7	37.2
Per cent reduction of volatile solids in digestors	64.6	47.9	59.4	52.0	60.9
Suspended solids in raw sewage in pounds per capita per year	48.8	53.7	42.8	54.1	45.9
Suspended solids in pounds per million gals. of sewage treated	1,483	1,356	1,250	1,643	1,338
Cost per million gallons of sewage treated	$ 14.45	$ 12.11	$ 12.61	$ 11.93	$ 12.16
Cost per capita per year	$ 0.48	$ 0.53	$ 0.41	$ 0.39	$ 0.42

TABLE II.—*Characteristics of Raw Sewage, 1935*

	Suspended Solids Total Lbs. per Month	B.O.D. Pounds per Cap. per Day	Population Equivalent Basis of .132 Lbs./Cap./Day	Temperature Degrees Fahr.	Hydrogen Ion Conc.	Dissolved Oxygen p.p.m.
January	286,560	.107	58,182	51	7.5	5.7
February	287,984	.113	61,357	54	7.4	5.6
March	246,760	.098	53,265	56	7.4	4.8
April	227,640	.103	55,970	56	7.4	4.7
May	332,640	.094	51,182	60	7.5	4.3
June	332,880	.114	62,106	63	7.4	3.7
July	216,106	.100	54,402	71	7.3	1.0
August	263,760	.126	68,568	76	7.1	0.0
September	242,820	.120	65,152	71	7.1	0.0
October	319,210	.131	71,500	70	7.2	.1
November	235,752	.117	63,947	62	7.5	2.4
December	314,400	.146	79,614	60	7.1	.4
Total	3,306,512	—	—	—	—	—
Average	275,543	.114	62,104	62	7.3	2.7
1931 Total	3,418,700	—	—	—	—	—
Ave.	248,891	.136	67,975	68	—	—
1932 Total	3,761,712	—	—	—	—	—
Ave.	313,476	.148	74,268	66	—	—
1933 Total	2,994,000	—	—	—	—	—
Ave.	250,000	.128	66,700	65	7.2	1.3
1934 Total	3,784,000	—	—	—	—	—
Ave.	315,333	.133	72,525	65	7.2	.7

Pounds of Suspended Solids

Per Capita per Year		Per Million Gallons of Sewage	
1931	48.8	1931	1483
1932	53.7	1932	1356
1933	42.8	1933	1250
1934	54.1	1934	1643
1935	45.9	1935	1338

TABLE III.—*Solid Matter Removed from Sewage, 1935*

	Screenings, Cubic Feet per Month	Grit, Cubic Feet per Month	Grease, Cubic Feet per Month	Suspended Solids,* Pounds per Month	
				Total	Volatile
January	33	390	40	260,690	169,150
February	72	150	40	268,056	157,680
March	74	100	80	228,850	141,290
April	83	90	60	214,632	125,202
May	36	140	140	315,630	154,980
June	49	0	70	317,112	162,936
July	39	200	30	207,176	112,518
August	52	200	145	248,640	186,480
September	100	300	90	232,596	158,472
October	62	90	200	298,660	200,020
November	70	170	200	218,691	144,243
December	46	0	200	292,785	216,150
Total	716	1,830	1,295	3,103,518	1,929,121
Per mil. gal	.29	.74	.52	1,255	780
Per cap. per yr	.01	.03	.02	43.1	26.7
1931 Total	2,095	5,616	—	2,246,000	1,398,340
Per mil. gal	.91	2.43	—	974	607
Per cap. per yr	.03	.08	—	32.1	20.0
1932 Total	1,655	3,512	—	3,267,000	1,999,300
Per mil. gal	.59	1.25	—	1,162	711
Per cap. per yr	.02	.05	—	46.7	28.6
1933 Total	1,656	5,918	2,519	2,766,000	1,778,000
Per mil. gal	.69	2.47	1.05	1,154	742
Per cap. per yr	.02	.09	.04	39.5	25.4
1934 Total	1,329	1,795	1,834	3,501,500	2,255,400
Per mil. gal	.58	.78	.80	1,520	979
Per cap. per yr	.02	.03	.03	500	32.2

* Computed from suspended solids determinations which are dried at 105° and ignited at 800° Centigrade.

During the year 1935 the treatment works removed from the Springfield sewage a total of 1,670 tons of solid material or 4.5 tons per day.

TABLE IV.—*Summary of Operating and Analytical Data for the Year 1935*

Rainfall In.	Sewage Flow		Secondary Treatment									Month	Chemical Results in Parts per Million															
			Returned Sludge			Mixed Liquor				Air	Settling Rate gals./sq. ft.		Suspended Solids			Volatile Solids			B.O.D. (5 day)			Free Ammonia			Org. Nitrogen (incl. Free NH₃)			NO₃
	Raw M.G.D.	Sec. M.G.D.	% of Inf.	Sus. Solids P.p.m.	Sett. Sol. 30 min.	Sus. Sol. P.p.m.	Sett. Sol. 30 min.	S.I.*	Aer. Period Hrs.	Cu. Ft. per Gal.			Raw	Pri. Eff.	Sec. Eff.	R.	P.E.	S.E.	R.	P.E.	S.E.	R.	P.E.	S.E.	R.	P.E.	S.E.	S.E.
2.10	9.2	7.7	19	9362	32	1893	6	33	4.9	.67	1054	January	144	96	13	94	66	9	100	77	7	11.0	11.0	0	15.4	14.6	1.40	11.0
1.57	8.9	7.5	20	10786	65	2280	10	42	4.9	.70	1043	February	164	105	11	97	64	7	109	79	5	11.0	11.0	0	20.2	18.6	1.28	8.8
2.90	10.4	7.7	20	8910	44	1823	8	43	4.8	.67	1066	March	124	87	9	76	53	5	81	66	5	8.5	8.5	0	13.4	12.6	1.12	10.0
3.39	10.8	6.5	21	7040	28	1418	5	39	5.6	.66	910	April	140	80	8	82	55	5	82	66	4	6.4	6.0	0	13.5	9.5	1.08	7.6
7.91	13.8	7.3	20	7490	18	2213	6	26	5.1	.63	1010	May	176	99	9	87	50	5	59	45	4	3.7	3.5	0	9.0	7.4	1.00	9.6
5.69	11.7	7.0	20	5555	14	1220	4	34	5.3	.62	977	June	190	86	9	99	54	6	84	64	5	6.4	6.0	0	9.4	8.6	1.04	9.0
5.43	10.0	6.9	22	4870	40	1117	7	67	5.3	.68	980	July	121	58	5	67	41	4	86	60	3	4.8	4.8	0	8.9	9.4	.96	5.0
1.23	6.5	6.5	23	6197	87	1531	24	153	5.5	.79	936	August	157	84	9	117	73	6	167	135	11	13.5	14.0	.12	24.5	21.7	1.48	6.4
3.22	4.8	5.1	28	4124	59	1196	11	90	6.5	1.06	788	September	190	91	8	131	72	7	215	139	13	19.0	20.0	5.0	31.6	27.6	5.66	7.0
2.13	4.5	5.3	28	5757	87	1622	19	117	6.2	1.08	821	October	233	101	15	158	69	12	251	157	22	17.5	16.5	3.7	24.4	22.8	4.56	6.6
4.59	8.8	6.2	27	4774	48	1383	10	72	5.4	.87	943	November	152	78	11	100	52	7	115	73	6	9.0	9.6	.7	17.4	15.4	2.20	6.4
1.06	6.7	7.6	22	5699	86	1302	12	93	4.7	.72	1088	December	160	83	11	118	64	8	188	123	14	12.4	12.4	2.6	17.7	17.7	4.00	8.0
3.43	8.8	6.8	22	6090	50	1583	10	64	5.3	.75	968	Average	163	84	10	102	59	7	128	90	8	10.3	10.3	1.1	17.1	15.5	2.14	7.9

* Sludge Index.

Digested Sludge Record for the Year 1935

Month	Beds	Tanks Lowered Inches	Pounds Wet Sludge	% Solids		Pounds Dry Sludge	Drying Days
				Total	Fixed		
January	2	30	210,000	8.64	57.2	18,150	
February	4	60	420,400	8.89	57.3	37,370	
March	6	96	671,900	8.64	58.1	58,030	
April	10	145	1,018,100	9.07	59.2	94,720	
May	1	15	105,500	9.78	61.7	10,300	
June	11	210	1,465,200	10.27	63.3	149,480	24
July	8	154	1,193,400	10.26	67.6	122,070	23
August	15	287	2,024,600	10.29	66.7	209,140	28
September	10	202	1,423,200	9.83	65.1	139,970	12
October	6	122	842,000	5.42	61.0	45,650	
November	3	60	416,700	4.51	56.4	18,800	
December	7	144	1,007,100	5.45	56.3	54,950	
Average	7	127	900,000	8.91*	62.1*	80,000	25*

* Weighted average.

TABLE V.—*Raw Sludge Data, 1935*

	Raw Sludge, Gallons per Day	Sludge Removed Per Cent Solids		
		Link Belt Tanks	Dorr Tank	Average
January	32,461	5.03%	7.87%	6.45%
February	36,221	6.51	9.54	8.02
March	37,794	5.46	6.16	5.81
April	35,907	4.97	6.13	5.55
May	37,376	8.93	7.37	8.15
June	41,570	3.43	5.14	4.28
July	42,000	4.89	6.83	5.86
August	48,632	2.55	3.08	2.81
September	46,300	2.70	2.99	2.85
October	46,297	2.90	3.33	3.12
November	42,139	3.76	4.58	4.17
December	43,287	3.17	3.65	3.41
Average *	40,832	4.02%	5.12%	4.57%
1931 Ave.*	—	2.97%	3.52%	3.25%
1932 Ave.*	—	3.89	4.14	4.01
1933 Ave.*	—	3.88	4.44	4.16
1934 Ave.*	40,154	4.14	4.61	4.37

Raw sludge is a mixture of Primary sludge, Waste Activated Sludge and solids which settle out of the supernatant liquor from the Digestors.

TABLE VI.—*Gas Production, 1935*

	Cubic Feet of Gas per Day	Cubic Feet per Capita per Day	Volatile Solids Added to Digestors, Pounds per Day	Cubic Feet of Gas per Pound of Vol. Solids Added	Average Temperature of Digestors, Deg. Fahr.
January	49,800	.69	5,456	9.1	100
February	54,914	.76	5,634	9.8	100
March	50,506	.70	4,558	11.1	98
April	47,496	.66	4,173	11.4	94
May	26,329	.37	4,994	5.3	89
June	42,867	.59	5,431	7.9	93
July	44,400	.62	3,629	12.2	99
August	51,027	.71	6,016	8.4	104
September	59,288	.82	5,282	11.2	98
October	69,284	.96	6,453	10.7	103
November	48,750	.68	4,808	10.1	95
December	66,437	.92	6,974	9.5	92
Average	50,925	.71	5,285	9.7	97
1931 Ave.	40,648	.58	3,831	10.6	82
1932 Ave.	37,678	.54	5,469	6.9	79
1933 Ave.	40,597	.58	4,940	8.2	87
1934 Ave.	53,851	.77	6,365	8.5	95

Connected population—72,000

The digestion facilities consists of six 40-foot tanks, each with a usable capacity of 30,000 cubic feet. Three tanks are equipped with Downes floating covers, two with fixed steel covers and one serves as a base for a gas holder. From January until August of 1935 four digestors were used for primary digesion and two for secondary. For the last five months the scheme has been reversed two being used for primary digestion and four as secondary tanks. This has resulted in better gas production but the primary tanks are very evidently overloaded so that beginning with January, 1936, they will be operated as three primary and three secondary tanks.

The low gas production during May, June and July was due to very heavy rainfall which carried much gas forming material away through the diversion chambers.

TABLE VII.—*Total Electricity Consumed by Sewage Treatment Works*

	Total Sewage Flow, Mil. Gal. per Month	K.W.H. Used per Month	Cost per Month	Cost per Mil. Gal. of Sewage	Purchased Horse Power per Mil. Gal. of Sewage	Total H. P. per Mil. Gal. of Sewage
January	239.7	25,400	$ 297.18	$ 1.24	5.9	21.4
February	210.9	17,200	201.24	.95	4.6	22.2
March	238.5	30,200	353.34	1.17	7.0	20.8
April	196.0	27,300	319.41	1.63	7.8	21.0
May	220.9	47,800	559.26	2.53	12.1	20.1
June	210.5	24,500	286.65	1.36	7.3	20.9
July	213.5	27,500	321.75	1.50	7.2	21.7
August	201.5	31,700	370.89	1.84	8.8	24.9
September	153.0	18,500	216.45	1.41	6.7	33.4
October	165.0	15,800	184.86	1.12	5.4	33.5
November	185.5	30,500	356.85	1.92	9.1	27.7
December	236.2	25,100	293.67	1.24	5.9	21.5
Total	2,471.2	321,500	$3,761.55	$17.91	87.8	289.1
Average	206	26,792	313.46	1.51	7.3	24.1
1930 Ave.	226	60,875	590	$ 3.22	—	—
1931 Ave.	192	68,833	709	3.79	—	20.7
1932 Ave.	234	115,650	1,110	4.94	—	28.7
1933 Ave.	200	56,300	541	2.70	15.7	28.3
1934 Ave.	192	31,092	345	1.79	9.0	28.4

A distinction is made between "*Total* Horse Power per Million Gallons of Sewage" and "*Purchased* Horse Power per Million Gallons" because a considerable portion of the power for aeration was furnished by the gas engine operating on gas produced by the digestion tanks.

The average cost of electric power used at the treatment works was as follows:

1931—$0.0103 per kilowatt hour
1932— 0.0096 " " "
1933— 0.0096 " " "
1934— 0.011 " " "
1935— 0.012 " " "

TABLE VIII.—*Electric Power Consumed by Aerators*

	Sewage Flow Through Aerators, Mil. Gal. per Month	K.W.H. Used by Blowers per Month	Cost per Month	Cost per Mil. Gal. of Sewage	Purchased Horse Power per Mil. Gal. of Sewage	Total H. P. per Mil. Gal. of Sewage
January	239.7	8,070	$ 94.42	$ .39	1.9	17.4
February	210.9	2,250	26.32	.12	.6	18.2
March	238.5	15,580	182.29	.76	3.6	17.4
April	196.0	14,180	165.91	.85	4.0	17.2
May	220.9	33,270	389.26	1.76	8.4	16.4
June	210.5	9,520	111.38	.55	2.5	16.1
July	213.5	12,060	141.10	.66	3.2	17.7
August	201.5	16,090	188.25	.93	4.4	20.5
September	153.0	2,460	28.78	.19	.9	27.6
October	165.0	0	0	0	0	28.1
November	185.5	13,450	157.36	.85	4.0	22.6
December	236.2	13,030	152.45	.64	3.1	18.7
Total	2,471.2	139,960	$1,637.52	$7.70	36.6	237.9
Average	206	11,663	136.46	.64	3.1	19.8
1930 Average	82	52,108	$ 547.00	$7.13	—	—
1931 Average	114	56,083	578.00	5.44	—	29.5
1932 Average	234	104,258	1,000.00	4.46	—	25.0
1933 Average	200	42,380	407.00	2.03	11.9	24.4
1934 Average	192	16,326	181.00	.91	5.0	24.4

See footnotes on preceding page.

TABLE IX.—*Operation Cost Data*

	Salaries and Wages	Power	Grounds Expense	Supplies	Miscellaneous Expense	Total for Month
January	$ 1,230.00	$ 220.73	$ 125.00	$ 332.61	$ 37.90	$ 1,946.24
February	1,291.00	325.97	0.00	292.58	62.10	1,971.65
March	1,241.00	307.59	71.65	309.83	62.22	1,992.29
April	1,362.00	340.72	494.43	285.30	487.68	2,970.13
May	1,324.00	402.11	229.50	410.69	166.99	2,533.29
June	1,341.75	334.12	259.74	369.58	61.02	2,366.21
July	1,557.00	302.89	219.75	329.78	65.44	2,474.86
August	1,585.00	290.98	241.00	480.84	191.34	2,789.16
September	1,611.00	362.42	221.85	503.12	84.76	2,783.15
October	1,815.00	227.48	125.00	412.14	137.28	2,716.90
November	1,690.00	309.24	0.00	744.12	40.20	2,783.56
December	1,632.00	301.98	0.00	473.29	322.62	2,729.89
Total	$17,679.75	$3,726.23	$1,987.92	$4,943.88	$1,719.55	$30,057.33
Average	1,473.31	310.52	165.66	412.00	143.30	2,504.78
1931	$17,072.00	$ 8,312.00	$1,831.00	$4,849.00	$1,297.00	$33,362.00
1932	17,626.00	13,336.00	1,278.00	3,408.00	1,212.00	36,861.00
1933	17,053.00	6,870.00	1,629.00	3,379.00	1,276.00	30,206.00
1934	16,431.00	4,181.00	1,795.00	3,904.00	1,167.00	27,479.00

For cost per capita and cost per million gallons of sewage see page 7.

Under the heading of "Supplies" is included—Miscellaneous Tools, Water, Oil, Fuel, Laboratory Expense and Replacements.

Under the heading of "Miscellaneous Expense" is included Motor Truck, Telephone and Telegraph, Printing, Office Expense, Insurance, Freight and Express, and Auditing.

The above figures do not include pumping costs.

TABLE X.—*Comparative Efficiency of Primary Settling Tanks*

As indicated by the removal of suspended solids and the concentration of primary sludge during 1935.

Date	Flow M.G.D.	Retention Period, Hours	Link Belt Tanks				Dorr Tank			
			Influent P.p.m. Sus. Solids	Effluent P.p.m. Sus. Solids	Per Cent Removal	Sludge Per Cent Solids	Influent P.p.m. Sus. Solids	Effluent P.p.m. Sus. Solids	Per Cent Removal	Sludge Per Cent Solids
July 18	7.3	1.1	173	68	60.7	2.92%	161	78	51.6	4.50%
" 25	10.6	.7	122	60	50.8	7.36	122	62	49.2	13.70
Aug. 1	8.1	1.0	169	52	69.2	3.65	148	75	49.3	3.91
" 8	7.2	1.1	195	79	59.5	2.80	218	82	62.4	4.26
" 15	6.7	1.1	229	71	69.0	2.44	205	84	59.0	2.62
" 22	6.8	1.1	167	85	49.1	2.42	157	88	44.0	2.37
Sept. 5	5.3	1.5	147	80	45.6	2.72	153	93	39.2	3.06
" 12	5.4	1.4	127	74	41.7	3.02	132	73	44.7	3.14
" 19	4.5	1.7	169	78	53.8	2.35	165	68	58.8	2.77
Oct. 10	6.5	1.2	386	134	65.3	4.47	366	219	40.2	4.02
" 17	5.2	1.5	262	61	71.7	2.18	262	102	61.1	2.92
" 24	5.5	1.4	248	81	67.3	2.24	282	79	72.0	3.33
" 31	4.3	1.8	160	73	54.4	2.71	172	79	54.1	3.06
Nov. 21	8.1	1.0	128	71	44.5	4.72	127	75	40.9	3.28
Dec. 12	7.5	1.0	205	66	67.8	3.78	187	87	53.5	4.22
" 19	7.7	1.0	214	67	68.7	2.90	205	73	64.4	3.64
Average	6.7	1.2	194	75	61.3	3.29	191	88	53.9	4.05

Excess activated sludge is returned to the raw sewage and is re-settled in the primary settling tanks.

The two units are operated in the same manner except that the Dorr Tank collecting mechanism is operated continuously whereas in the Link-Belt tanks the flights are operated only one hour each time sludge is drawn.

THE VALUE OF LABORATORY TESTS FOR THE CONTROL OF THE ACTIVATED SLUDGE PROCESS

From *The Digestor*, May, 1936

CLARENCE W. KLASSEN

Chief Engineer, Ill. State Dept. of Health

CONTROL TESTS AND WHAT THEY MEAN

The laboratory is one of the most essential units in an activated sludge plant. Proper operation is impossible without some laboratory control. We will list the principal control tests and briefly discuss their use and application to practical plant operation. The actual procedure for making each test is outlined in the book "Standard Methods for Examination of Water and Sewage" which may be obtained from the American Public Health Association, 50 West 50th St., New York City. You should have the 8th Ed. (1936) now on sale.

The following tests will be discussed: (1) Activated Sludge Settleability; (2) Suspended Solids; (3) Sludge Index; (4) Dissolved Oxygen; (5) pH; (6) Settleable Solids; (7) Biochemical Oxygen Demand; (8) Nitrates; (9) Methylene Blue Stability; (10) Turbidity.

Activated Sludge Settleability.—The main value of this test is to show the rate at which activated sludge will settle, an important indication of whether the sludge is in good or bad condition. While the sludge is settling in the 1000 c.c. cylinder the volume occupied by the settled sludge after 10, 20, 30, 45 and 60 minutes should be noted and a curve drawn such as Figure 1. (Sample taken from mixed liquor leaving aeration tank).

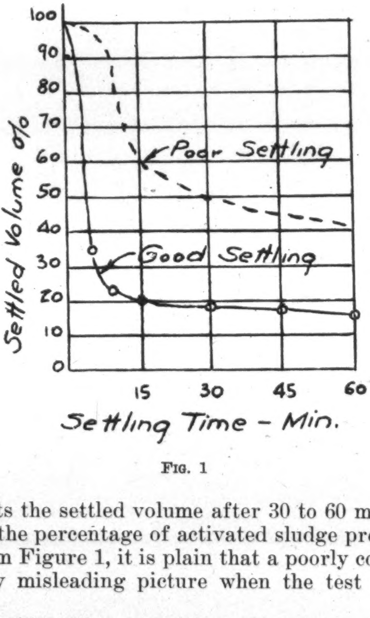

FIG. 1

At some plants the settled volume after 30 to 60 minutes settling is used to estimate the percentage of activated sludge present in the aeration tanks. From Figure 1, it is plain that a poorly conditioned sludge may give a very misleading picture when the test is used for this purpose.

Suspended Solids.—This very important determination is useful as a control test and also for measuring plant efficiency and should be made in every activated sludge plant. For operation control it is used to determine the actual *weight* of solids in the mixed liquor (aeration tank contents) or return sludge, and thus tells how much sludge is being carried regardless of the condition of the sludge. As a plant efficiency test, the determination will show the actual weight of suspended matter (does not include *dissolved* matter) in the raw sewage, primary tank effluent and final effluent, thus showing the actual removal in each part of the plant.

Sludge Index.—This index or number is a measure of the "density" of the sludge or the volume in cubic centimeters occupied by 1 gram of sludge after 30-minutes settling. For instance, if the sludge settles to a volume of 150 cc. (15%) in a 1000 cc. cylinder after 30 minutes and if the suspended solids in the same sample is determined as 950 parts per million (.095%) the sludge index = 15% ÷ .095% = 158. After you determine the sludge index in your plant during normally good operation, the daily determination of this number will assist you in keeping a check on the varying conditions of the activated sludge.

Dissolved Oxygen.—It is important that you know approximately how much dissolved oxygen is present through the aeration tanks and in the plant effluent. A method for finding the dissolved oxygen in the mixed liquor is described below.

pH.—If a strong alkaline or acid substance is present in the sewage (possibly an industrial waste) the organisms working in the aeration tank may become "sick" or be killed. The pH test quickly tells if such a condition exists. This determination is also helpful when it is necessary to use chemicals to correct certain types of trouble.

Settleable Solids (Imhoff Cones).—An efficiency approximation which tells you whether or not your settling tanks are working properly. Very little solids that will settle should be present in a primary tank effluent and, of course, *none* should be present in the plant effluent.

Biochemical Oxygen Demand.—This determination, commonly called the "B.O.D." is an excellent means of measuring efficiency of treatment. The amount of oxygen needed to render the organic matter in the sample unobjectionable or to "stabilize" it, is determined. The B.O.D measures *all* of the organic matter present that is subject to stabilization, both the suspended and dissolved forms. When the B.O.D. of the raw, settled sewage and final effluent is determined, the effectiveness of each part of the plant is shown. The raw sewage B.O.D. is important in itself as it gives an accurate measure of the varying load on the plant.

Nitrates.—This is a plant effluent determination which indicates the point to which purification has taken place. After nearly all the organic matter has been stabilized, nitrates begin to form and the amount shown by the test tells the operator whether or not he is producing a thoroughly treated effluent.

Methylene Blue Stability.—Is also an effluent test which indicates the amount of available oxygen present to meet the requirements of any objectionable matter which may be left in the effluent after treatment. The blue color leaves the sample as the available oxygen is used up.

Turbidity.—A good activated sludge plant effluent is usually clear and sparkling. The turbidity test gives a gradation of the clarity by number. Since the test can be made quickly and easily, it is useful in the small plant for checking the effluent and may give warning of approaching trouble.

Dissolved Oxygen in Mixed Liquor.—Activated sludge in mixed liquor uses up oxygen very quickly. So quickly, in fact, that an estimation of the dissolved oxygen made on the clear water after the sludge has been allowed to settle out, may indicate results which are entirely too low. This is not because of any fault of the test, but because during the short period of settling required, all or much of the oxygen will be used up. One way out of this difficulty is to stop the activity of the sludge at the moment of collection of the sample, by the addition of copper sulphate. The procedure following is useful:

Place 10 c.c. of ~~a~~ 10 per cent solution of copper sulphate (10 grams to 100 c.c. of water) in a quart bottle with a wide mouth. Fill the bottle full of mixed liquor, mix quickly and allow to settle until there is sufficient clear supernatant liquid to fill a dissolved oxygen bottle. Siphon into D. O. bottle and proceed with the regular dissolved oxygen test, but following addition of the alkaline iodide solution, add the acid as soon as the precipitate has settled for about one-half an inch. Then titrate the iodine as usual.

Results by the procedure, while approximate, are sufficiently accurate to be used as an operation control.

Reviews and Abstracts

H. W. STREETER

SOME EXPERIMENTS ON THE OXYGEN DEMAND OF AN ACTIVATED SLUDGE

BY H. H. GOLDTHORPE

Paper presented at a meeting of the North-Eastern Branch of the Institute of Sewage Purification, Leeds, England, February 22, 1936, and abstracted, together with discussion, in *The Surveyor*, **89**, 351–53 (February 28, 1936) and **89**, 379–80 (March 6, 1936).

Extended observations with Huddersfield activated sludge indicate very clearly differences in time of purification of sewage as between the laboratory experiments and the full scale plant. Because the laboratory sludges were subjected to much better aeration and circulation, the rôle of oxygen in the activated sludge process was studied intensively.

Review of Results of Various Workers.—Regarding the rate of solution of oxygen in water and sewage, the author reviews the work of previous investigators and tabulates their results. For raw sewage, this rate has been found to vary with the pH, with the minimum at pH 8 and increasing on either side of this figure. For the hypothetical case of a bio-aeration plant having channels 1 meter wide and 1 meter deep filled with a channel sludge containing 2000 p.p.m. of suspended matter employing the observations of various workers, the rate of supply of oxygen would vary from .0000049 to .00087 grams per gram of sludge per minute. Comparable data of various workers concerning the short period oxygen demands of different sludges range from .000152 to .00090 grams of oxygen per gram of sludge per minute. The matter of a sufficient supply of oxygen for sludge requirements is therefore of prime importance. Among other factors affecting oxidation rates is the pH of the liquid as investigated by Barcroft.

Experimental Studies.—Rates of oxygen consumption of activated sludges were observed using an apparatus in a constant temperature room by which an inclosed volume of air was bubbled through a known volume of activated sludge by means of a mercury pump. The progress of oxidation is given for various types of sludge by means of tabulated data showing the amounts of oxygen used up at short intervals (30 minutes or less) for periods as long as 42 hours. Putting these results in line with the tabulated results of other workers it is found that for Huddersfield sludges the oxygen demand is:

1. In milliliters of oxygen per liter of sludge per hour, 12 to 2.
2. In grams oxygen per gram of sludge per minute, .00017 to .000025.
3. Nordell Number (oxygen in p.p.m. per hour), 17 to 3.

Values (1) and (3) are comparatively low, while (2) is in agreement with that of two American workers. Variations are probably due to the different natures of the compared sludges. The results are representative of Huddersfield sludges under normal working conditions. A 10 per cent sludge, containing about 2000 p.p.m. of suspended matter requires about 10 mls. of oxygen per hour liter in earlier stages, half of this amount after 24 hours aeration and after three or four days aeration a very small amount of oxygen is used.

Oxygen Demands by Dilution and Depletion Methods.—For arresting the absorption of dissolved oxygen by activated sludge, two reagents have been found most suitable:

1. Copper sulphate as suggested by Palmer and Beck of the Chicago Sanitary District was used by Kessler and Nichols but unfortunately the cupric ion liberates an equivalent of iodine and corrections are necessary unless only simple time difference experiments are to be performed.

2. Mercuric chloride as a germicide acts in solution by combining chemically with the protein of the micro-organisms and hence its efficiency varies inversely with the amount of organic matter present. About 10 mls. of a 5 per cent solution of mercuric

chloride solution are necessary for one liter of a 10 per cent sludge. If, however, the concentration of $HgCl_2$ exceeds about 400 p.p.m., mercuric iodide is precipitated in the Winkler-Rideal test and more KI is required to redissolve the precipitate. Mercuric chloride tended to disperse the Huddersfield sludge and prevent settlement. Therefore, a suspension of aluminum hydroxide is added immediately after the $HgCl_2$ by which procedure a clear supernatant is obtained in less than ten minutes.

Neither $HgCl_2$ or $CuSO_4$ in the above concentrations arrests completely the absorption of oxygen by Huddersfield sludges over 24 hour periods but is sufficiently accurate up to 5 or 6 hours. In undiluted sludges it appears that side by side with the biological oxidation runs a direct chemical oxidation which naturally is not arrested by sterilizing agents. This chemical oxidation is considerable, especially in the early stages, in sewages containing much trade waste.

Diluted Sludges.—"In diluting sludges, the fact that the sludge may contain oxygen in solution has to be taken into account. Also, if the sludge just previous to dilution has not been receiving its full requirements of oxygen it may act on its reserves, as we strongly suspect to be the case. For instance, our sludge contains some 6 per cent of iron, partly as ferrous and partly as ferric. Dyestuffs, such as methylene blue, by their reduction of leuco compounds, may tide over the sludge during a period of oxygen deficiency, to be re-oxidised when an excess of oxygen is available. In this way sludges in the earlier stages of oxidation, or sludges which have passed through an anaerobic phase, e.g., in a settling tank, may exhibit very large immediate demands. This is demonstrated when diluting sludges, while it is not shown by the other two methods.

"When worked out in grams of oxygen per gram of sludge, the immediate demand is anything from ten to 100 times the normal demand per gram of sludge per minute. A study of this demand might tell us a little more about our sludges. It may simply be a dilution effect, or again, it may be the satisfaction of a demand created after working under conditions in which the normal demands are not completely fulfilled. This immediate demand does decrease with aeration, but incubating sludges anaerobically for some hours (eight to twenty-four) affects the demand only slightly, while the power of absorbing oxygen in a normal way is destroyed.

"If this immediate demand manifests itself when the sewage and sludges have relatively different concentrations, as, say, between day and night sewages, before and after week-ends, general holidays, or during periods of sudden storms, a greatly increased load will have to be met by the plant."

To illustrate this immediate effect the results of an experiment are tabulated which show that a sludge aerated for 3 hours gave an oxygen demand of .000027 gram per gram of sludge per minute, and that by dilution the demand for the first two hours was .000052 gram per gram of sludge per minute, for the second two hours .000024 gram of oxygen while the immediate demand was .0065 gram of oxygen per gram of sludge.

Discussion.—Mr. J. H. Garner, President of the Institute of Sewage Purification, in opening the discussion, emphasized the need of definite knowledge concerning the relationship between the amounts of oxygen taken up and the amounts of organic matter in the liquids under examination, and whether any connection between the two existed, by means of which the results of various observers could be compared on a proper basis. Because of the low oxygen saturation capacity of water—about 10 p.p.m.—and the consequent difficulty of providing a reserve of dissolved oxygen, the rate of purification of any liquid was limited. Hence, there might be a possible advantage in diluting a strong sewage with clean water or purified effluent to reduce the oxygen consumption rate during the treatment process. Fowler had in fact obtained improved efficiency by this method in the treatment of spent gas liquors on filters where dilutions of 1 in 10 and 1 in 20 were employed. A similar method of dilution was practiced at the Rotherham bio-aeration sewage treatment plant.

Mr. J. Hurley (Halifax) referred to the confusion caused by the immediate oxygen absorption phenomenon in a test designed for biological absorption and pointed out that in the case of sewage plant effluents where the test was used as a measure of pollution, the immediate demand was all the more harmful and should not be corrected for.

Mr. J. H. Edmondson (Sheffield) in further discussion of the immediate oxygen demand referred to the pioneer work of Nordell on this subject who had stated that probably activated sludge held a reserve of oxygen through absorption upon the floc surfaces. It was possible that this phenomenon acted as a reservoir through which atmospheric oxygen passed to be used for oxidation purposes and that the depletion of this reserve might be the cause of the immediate demand of a sludge. He suggested that the returned activated sludge, which usually had little if any dissolved oxygen and a high immediate demand might be returned in small quantities at a number of points in the aeration tank and thereby reduce the dissolved oxygen reserve at the inlet end and satisfy this immediate sludge demand as well.

Mr. J. M. Wishart (Shipley) was of the opinion that the narrow limits of pH emphasized the biological nature of the activated sludge process. He also inquired if sufficient oxygen had been introduced into the liquids in some of the experiments and whether any work had been done using oxygen instead of air.

Mr. W. D. Scouller (Huddersfield) stressed the importance of recovering the weight of oxygen taken up per unit weight of activated sludge. He suggested that the gravimetric values and the volume accupied by the sludge should always be recorded.

The two things brought out by the paper were (1) introduction of an apparatus for determining oxygen absorption of sludge by bubbling air through it (a device evidently similar to that developed by Theriault and McNamee; cf. THIS JOURNAL, May, 1934. Abstractor) and (2) a method of estimating the amount of oxygen taken up by the dilution process. The use of aluminum hydroxide in conjunction with mercuric chloride was very much better and quicker than any other method.

In reply to the discussion the author suggested that it might be advisable to correlate the oxygen demand in grams with the unit weight of volatile matter as Sierp had done rather than with weight of sludge. He pointed out the difference between diluting sludges with distilled or tap water as compared with purified effluent. In the first case changes in dissolved solids, osmotic pressure and other physical effects might seriously affect the results. Concerning the immediate demand of sludges, this demand persisted until the end of the purification. If more oxygen could be introduced in the earlier stages of the aeration tank where deoxygenation was most severe, more rapid purification would result.

J. K. HOSKINS

CENTRALIZED SEWAGE PURIFICATION WORKS AS OPPOSED TO SEPARATE UNITS

BY VALENTINE H. LEWIN

Paper read at a meeting of the Metropolitan and Southern Branch of the Institute of Sewage Purification, London, England, March 14, 1936.

The author enumerates the advantages and disadvantages of treatment of sewage at a single central plant as compared with disposal at a number of smaller works.

The advantages of the centralized plant as stated are:

1. Transfer of responsibility for proper sewage disposal from individual authorities to a central board.
2. Liberation of valuable land occupied by numerous small plants.
3. Equalization of sewage quality and strength resulting from mixing sewage and wastes from larger population groups.
4. Easier supervisory control of one works by River Conservators.
5. Provision of employment to Consulting Engineers and contractors on a grand scale.
6. Extension of scope of specialized workers in sewage disposal.

Disadvantages of central plants are:

1. The detrimental effect upon streams of the discharge of even good effluents of large volume at one point.
2. The large capital cost of construction both of the sewerage system and disposal works.
3. The collection of huge quantities of sludge to be disposed of in one locality.
4. Magnification of troubles where breaks in operating efficiency occur.

5. Reduction in employment of skilled and unskilled labor.

The author suggests that more extensive research is needed to simplify sewage treatment methods before the " Centralization " idea can be the undoubted " Master Method " of sewage purification.

J. K. Hoskins

INSPECTION OF THE GRAVESEND CORPORATION SEWAGE DISPOSAL WORKS

By Ronald Hicks

This description of the Gravesend plant was prepared in connection with the visit, on May 2, 1936, of members of the Metropolitan and Southern Section of The Institute of Sewage Purification, reported in *The Surveyor,* **89**, 671–72 (May 15, 1936).

The works are located on the Denton Marshes, and because of the insecure nature of the ground, are supported on piles which extend to a depth of 30 feet through mud to a gravel stratum 4 feet thick.

The sewage, entirely domestic, except wastes from slaughter houses, is exceptionally strong and is contributed by 36,000 peopde. The average dry weather flow is 650,000 g.p.d. or about 18 gallons per capita. Reasons for this low flow include hard water supply which is not used freely and insistence on water saving.

Analyses of the typical weighted 24 hour daily samples of the crude sewage and effluent are:

	Figures in P.p.m.	
	Crude Sewage	Effluent
Alkalinity (as H_2SO_4)	700	
Chlorides (as Cl)	350	
Free and saline Ammonia as N	75	
Albuminoid ammonia as N	16 to 26	4 to 6
4 hours oxygen absorbed at 80° F.	150 to 250	35 to 45
B.O.D. Royal Commission	600 to 1500	100 to 200
Suspended solids (Gooch crucible)	500 to 600	

The Treatment Plant.—On entering the plant the sewage passes through a " Garfield " type rotary screen with 1″ mesh and through a measuring flume to 4 upward flow Dortmund tanks of a total capacity of 300,000 gallons, by means of which the settleable solids are reduced from 10.5 to 1.5 mls. per liter (Imhoff cone test).

The tank effluent is treated by an activated sludge plant of the diffused air type which has a total capacity of 260,000 aeration and reaeration and 229,000 gallons settlement tanks. Because of the location of the works on a tidal river only partial treatment is necessary so that the effluent is of much lower quality than usually required.

Operating Conditions.—Overload conditions on Monday and Tuesday (wash days) affect the sludge seriously so that it has been essential to augment normal reactivation by adding ferric chloride to the returned sludge. This chemical is prepared at the plant by chlorinating copperas, though it may be possible shortly to prepare it directly from tin cans and chlorine.

A high oxygen supply (2 cu. ft. per gal. per min.) is required to keep the sludge in condition and the rate of purification is remarkably slow. A small amount of dissolved oxygen is generally present in the mixed liquor entering the settlement tank but very little can be found in the reactivated sludge entering the mixing channel. The sludge contains many filamentous growths and usually has a slightly sour odor. It readily settles at all times except following rain periods. When in very poor condition the bacterial content is very high, no ciliates are to be found and very few flagellates or amoebae. With improvement bacteria diminish, amoebae increase together with ciliates such as Vorticella and Paramoecia. All of the surplus activated sludge is returned to the raw sewage with very beneficial results and a negligible increase in the volume of preliminary settling tank solids.

Sludge Digestion.—The preliminary sludge is removed twice daily from the Dortmund tank to the preheating tank of the primary digestion tank, where during a 12-hour detention period it is heated to 85–90° F. The heated sludge is lowered into the main digestion tank displacing sludge which is passed into the secondary digestion tank. The tanks are maintained at about 80° F.

Gas production is about 0.9 to 1.1 cu. ft. per person per day and the general analysis is:

Methane	70%
Carbon dioxide	25%
Hydrogen	2%
Nitrogen	3%

The gas is used to drive a 47 h.p. gas engine supplying compressed air to the activated sludge plant and for heating, lighting, cooking and laboratory. It is not possible to separate the liquor from the digested sludge and the entire mass from the secondary digestion tank is passed into sludge lagoons or to drying beds. The digested sludge is odorless and is sold to local farmers at 6d. per ton.

J. K. Hoskins

IMPROVING THE EFFICIENCY OF ACTIVATED SLUDGE

By H. C. Whitehead and F. R. O'Shaughnessy

The Surveyor, **89**, 407–10 (March 13, 1936)

The authors, in this paper, review recent research work dealing with the nature and characteristics of activated sludge and, supported by their own observations of these matters, outline procedures that may be helpful in cases where for various reasons, activated sludges of poor settling qualities are encountered.

A necessary essential of activated sludge is prompt settling in the clarification tank. A normal rate of settlement of good sludge built up from domestic sewage is 8 ft. per hour. Obviously, any increase in this rate, without decrease in purification efficiency, would reduce the volume and hence the cost of settling tanks.

Physical Basis of Activated Sludge.—The physical basis of activated sludge is a gelatinous matrix of protein-like character produced by bacterial agents in water containing suitable nutrient substances and in the presence of oxygen. Oxygen, although in minute amounts, is essential for the formation of zoogleal masses which the authors have associated with this gelatinous matrix by means of which the individual sludge flocs are built up; a process of integration under the influence of the living agent. This reaction proceeds best in a liquid of pH 7.0 to 7.5 but will function in the range well below pH 7.0 to well over pH 8.0. A substantial reserve of alkaline material, such as bicarbonate of lime is helpful to balance the drop in alkalinity which occurs when oxidation is carried into the nitrification stage.

This activated sludge principle is widely distributed in nature. It may be observed in dilute sewage after standing several hours exposed to the air, it occurs in the slimy film on gravel in beds of polluted streams and in the fine silt of polluted estuaries binding together the fine particles. Such materials, aerated in laboratory vessels with weak sewage, will generate a material indistinguishable from activated sludge.

The authors also confirmed Fowler's observations that silt or other fine particles of crystalline inorganic matter act as nuclei for the necessary bacteria. Moreover, by aerating a mixture of tap water with sewage sufficient to bring the ammonia up to 1 p.p.m. and fine river silt, a rapid purification of the liquid is effected and at the same time the silt is changed to a dense, dark colored material.

Possible Applications of the Process.—This principle was applied on a laboratory scale to the treatment of a drinking water supply impregnated with organic matter, bacteria and algae. An activated material was worked up by preaeration of the water to be filtered and to which silt had been added. The results indicated that such pretreatment might be very effective and it is now proposed to test the process on a semi-works scale plant. Various materials were used as silts including river silts, fine sand, cement, clay suspensions, fullers earth and red marl, all of which, except cement, gave definite but varying results. However, only particles of 0.02 mm. or less down to those approaching colloidal dimensions were incorporated in the floc and larger sizes were rejected. Red marl in the proportion of 25 per cent of the dry matter in an ordinary good activated sludge gave the best clarification.

Recent Research Work.—The author reviews briefly the work of Theriault on the biozeolitic properties of activated sludge and that of Butterfield on isolation and determination of the characteristics of zoogleal bacteria isolated from activated sludge in which it was found that some inert material was necessary as a nucleus for floc formation. Earlier authorities are also quoted to demonstrate the consensus of evidence that the aeration of the living agent in building up zoogleal masses in activated sludge is highly specific, and that the purifying power of activated sludge depends upon this gelatinous matrix.

General Nature of Action.—In a series of experiments the authors mixed fine suspensions of materials of different densities with activated sludge with the view of improving its settling properties. Finely ground marl, sand, ignited sludge ash and manganese dioxide were added to sludge in the form of a suspension in water. Generally a definite minimum quantity of each material was required to improve the settling properties of the sludge, but beyond this minimum amount, the rate of settlement increased with further additions of the material added. Also, the denser the material the better the settlement obtained. Experiments were later extended to a large scale activated sludge plant of 2 m.g.d. capacity. Although the effluent of this plant is normally good, marl added to the sludge entering the aeration chamber resulted in a brilliant effluent and a better settling, denser sludge.

J. K. Hoskins

DISCUSSION OF TWO PAPERS ON ACTIVATED SLUDGE BY MESSRS. ARDERN AND LOCKETT

The Surveyor, **89,** 515–17 (April 3, 1936) and **89,** 545–47 (April 10, 1936). See This Journal, **7,** 519, 524 (May, 1936).

Mr. Lockett, in introducing the papers reiterated what had been stated in the text, that of all the tests tried the microscopical examination was far superior for judging the condition of activated sludge and never failed to give a true indication of its character. Regarding the paper on pretreatment of occasional abnormal sewage, he stated that although the authors still firmly believed in the efficiency of the biological methods as used at Manchester, yet the value of chemical precipitation as a temporary or occasional device, was being tried. Despite the advances in chemical precipitation processes in America, he agreed with Imhoff that it was only an adjunct to biological methods. He also emphasized the importance of a short period of pre-aeration—three to ten minutes—followed by a short period of settlement in the pre-treatment process ahead of the activated sludge plant. By this procedure it seemed possible to deal with very strong sewages in about one-third of the time.

Dr. W. Watson (Burnley) suggested a definition for conditioned sludge as one which was ready and eager to commence again purifying a sewage and one which would commence the process immediately and do it well. He did not agree with the authors that if a sludge settled well it was necessarily in good condition. He had found that when his activated sludge was bulking for any definite strength of sewage and any definite period of detention in the aeration tank, the effluents were better than at any other time.

Rather than determining the dissolved oxygen in the supernatant of the mixed liquor of sludge, he suggested that a better test might be to shake the mixed liquor sample taken from the end of the process until it was saturated with oxygen, let it stand for a definite period—10–15 minutes—then stop the absorption of oxygen by some chemical method and estimate the amount of oxygen absorbed. This would indicate the condition of the sludge because the better its condition the less would be its demand for oxygen.

Experimental studies of rates of oxygen demand of activated sludge, Dr. Watson stated, have shown that after purification of the sewage ended, oxygen was still used up at a constant rate, showing that the sludge was using it for its own internal purposes. When this condition existed he considered that the sludge was thoroughly conditioned.

In regard to the value of pretreatment of occasional strong sewage, Dr. Watson made the point that such occasional overloads reduced the efficiency of the activated sludge process for a whole week because recovery was only gradual. Therefore, effective pretreatment stepped up efficiency not only for the occasional periods during which it was employed but for much longer times. Filters recovered much more rapidly.

Mr. F. W. Allen (Bolton) referred to rates of settlement of sludges and observed that these are not always correlated with sludge condition. Bulking sludge at Bolton settled at a uniform rate, in contrast to the first rapid drop of non-bulking sludge, and the supernatant was much clearer and free from solids. He suggested that differences in specific gravity between the sludge and its liquid and the electrical condition of the sludge, *i.e.*, pH, might be correlated with settlement rates.

Mr. Barlow (Denton) observed that to add alumino-ferric at the rate of 120 p.p.m. as mentioned by the authors, would be very costly and Mr. Ledson (Leigh) was of the same opinion. Lime and copperas was much cheaper and gave better results, both because the flocs were larger and also because settlement was more rapid. The best precipitant ever used at Leigh was lime and ferric chloride.

Mr. E. J. Shaw (Stockport) stated that they still used lime in connection with the operation of their bio-aeration plant. Copperas also was added at the rate of about 1 grain per gallon and resulted in improved effluents.

Mr. E. H. Arrowsmith (Bredbury and Romiley) classified sludges as (1) filamentous, (2) flocculent and (3) very heavy. When bulking was occurring (1) was predominant; (2) was the ideal condition and was accompanied by a preponderance of carchesium and vorticelli; (3) resulted in a cloudy effluent.

Mr. Lockett, in reply to the discussion defined a sludge in good condition as one which would both purify sewage and settle rapidly. His experience had been that if aeration conditions were correct, the bulking problem did not occur. Although pH and difference in specific gravity of the sludge and its liquid were important factors affecting rate of settlement, the dissolved oxygen content of the mixed liquor was the most important of all. Better settlement of sludge following a rainstorm was always accompanied by a high dissolved oxygen content in the mixed liquor. Concerning the expense of alumino-ferric treatment, although it was high it appeared justifiable in view of the short periods it would be used. There was some objection to using copperas and ferric chloride was rather costly.

J. K. Hoskins

SOME DEVELOPMENTS IN SEWAGE WORKS ANALYSIS

By C. Lumb

Paper read before the North Eastern Branch of the Institute of Sewage Purification held at Leeds, England, March 28, 1936. Abstract in *The Surveyor,* **89,** 495–97 (April 3, 1936), and discussion **89,** 563–65 (April 17, 1936).

The author discusses in considerable detail quantitative analytical procedures and their limitations of tests for three constituents—colloidal matter in sewage and moisture and grease in sludges.

1. *The Estimation of Colloidal Matter in Sewage Liquors.*—The test for colloidal matter used at the Halifax Sewage Works laboratories, first discussed by Holyroyd and later by Edmondson and Lumb has been recently improved. Briefly, the procedure is to determine the total suspended matter by Gooch crucible or centrifuge and deduct this from the true suspended matter plus colloids, which latter have been precipitated by

suitable acidification. The remainder so obtained constitutes the true colloidal matter plus extremely fine "pseudo-colloidal" particles which for the purpose may be included with the true colloids. The test depends upon careful acidification of the sample to a pH of 3.0, gentle stirring for 7–10 minutes followed by collection of the deposited solids by centrifuging after standing one day.

Analytical data, illustrated by diagrams, are presented to show that for various types of sewage and effluents, the maximum precipitation occurs in the pH range 2.9–3.4 or an average of pH 3.1. Better precipitation results are obtained by using hydrochloric rather than sulphuric acid. Observations of the effect of various standing periods after acidification, upon the results indicate that whether the deposits are separated by Gooch or centrifuge, the precipitated sample should be set aside for one day before the separation is undertaken. Comparison of the Gooch crucible and centrifuge methods for collection of the precipitated colloidal matter indicate the superiority of the former, providing that N/1000 HCl is used for washing the deposit free from soluble matter. If preferred, the centrifuge method may be used, giving 5 minutes centrifuging (speed not stated), re-suspending in N/100 HCl and re-centrifuging 15 minutes. Analytical data are presented to show that all of the organic colloidal matter originally present in the sample is precipitated by the acid and retained by the Gooch crucible. However, inorganic constituents such as calcium, iron and phosphates may be leached out of the suspended and precipitated matter to the extent of 18 p.p.m. more or less.

From tests on sewages from other places, the author suggests the procedure may be of general application for controlling precipitation processes, for indicating the secondary sludge likely to be produced on subsequent oxidation treatment, for indicating the tendency to "ponding" on filters and for determining the amount of secondary sludge produced in activated sludge and sprinkling filter plants.

2. *The Estimation of Moisture in Wet and Partially Dewatered Sludges.*—Errors in the determination of moisture by the heat drying method may be considerable because substances other than water may be driven off and recorded as water. The distillation process, employing some liquid organic solvent having a higher boiling point than water avoids this error. The use of xylene by the Dean and Stark method and as applied to sewage sludges by Bach has certain disadvantages. The Perchlorethylene method described by Steward (*Jour. Text. Inst.*, **24**, T 98 (1933)) has proven very satisfactory and free from the defects of the xylene technique. A weighted quantity of the sludge is distilled with perchlorethylene (boiling point 119° C.) in a special type of still by which the excess of perchlorethylene automatically is returned continuously to the boiling flask. All the water vapor is swept along to a graduated tube where it separates sharply in an upper layer above the perchlorethylene. The distillation process is continued for 5 minutes after the water layer has ceased to increase in volume. The maximum error is about 0.33–0.35 per cent of the moisture content of the sample examined. The design of a modified tube to permit more accurate reading of the volume of the water layer is under way but no results from its use are yet available.

3. *The Determination of Grease in Sludges.*—The standard solvent for the extraction of fatty matter from sludges for the grease test in England is petroleum ether. Following the published results obtained by Knechtges, Peterson and Strong (THIS JOURNAL, **6**, 1082 (1934)) using cholroform, comparative tests of the two solvents were made on sludge, secondary sludge and digested sludge, the results of which the author presents in tabular form. With all types of sludge, chloroform gave superior extraction to petroleum ether, while carbon-disulphide in general gave intermediate results. The author suggests that if further tests from other places confirm these observations the use of chloroform be made standard procedure.

Discussion.—The discussion dealt with interesting details of analytical methods generally not amendable to abstracting. Mr. J. M. Wishart (Shipley) noted that in the proposed method for determination of colloids, the actual figure obtained was one by difference, which depended on the value of the suspended matter. Because of divergent results possible in the suspended matter determinations, a standardization of the Gooch crucible method should be considered. Possibly a standardized centrifuge method would be better for estimating the true suspended matter.

Dr. H. H. Goldthorpe (Huddersfield) suggested that the difference in action of HCl and H_2SO_4 might be due to the difference in the mobility of the Cl ion and the more complex SO_4 ion or the difference in chemical action on the protective coatings of the pseudo-colloids. Floating grease by the centrifuge method might account for results different from those obtained by the Gooch procedure.

Mr. J. H. Garner (West Riding of Yorkshire Rivers Board) observed that instead of allowing a day or more for settlement of the acidified sample, warming was found to have the same effect and would probably expedite the test.

J. K. Hoskins

PRELIMINARY TREATMENT AND INSPECTION OF TRADE WASTES

By E. J. Shaw

Paper presented at a meeting of the North-western Branch of the Institute of Sewage Purification, March 6, 1936, and abstracted, with discussion, in *The Surveyor*, 89, 445, 457 (March 20, 1936).

The provisional limiting standards for trades wastes discharged into the Stockport sewers are:

Oxygen absorbed from N/80 $KMnSO_4$ in 4 hours at 80° F.	1200 p.p.m.
Alkalinity or acidity as H_2SO_4	2000 p.p.m.
Suspended solids	400 p.p.m.
Temperature not to exceed	110° F.

Preliminary treatment by the industry is required for various wastes to meet these requirements before discharge to the municipal sewers. Such treatment varies but generally is accomplished by screening or settling in tanks. In the case of spent sulphide dye liquors, the sodium sulphide is oxidized with sodium bichromate or sodium hypochlorite in tanks before discharging to the sewer. The liquor from mercerizing plants is strongly alkaline and unless treated for the recovery of alkali, is diluted with wash liquors before entering the sewers. Vat washings and residues from breweries are passed through filter presses for recovery of the yeast; the barrel and bottle wash waters are screened. Wastes from a tripe dressing plant contain fleshy particles and fat in suspension and usually have a fairly high temperature. These liquors are passed through a grease trap, which is an ordinary settling tank equipped with deep baffles and submerged cross walls.

Periodic inspections of these preliminary treatment plants are necessary to see that the requirements for effluents are met. Sludging of settling tanks and keeping of screens in proper repair are otherwise generally neglected.

Discussion.—Captain W. E. Speight (Bolton) considered that Stockport was very lenient to industry in their limit of wastes content received into the city sewers, particularly in the solids and acid content. He recalled an experience in which waste from a mercerizing plant caused considerable trouble at the municipal sewage treatment works where alumino-ferric was used as a precipitant. No precipitation took place because as fast as hydroxide was precipitated by the alumino-ferric it was redissolved by the excess of caustic soda.

Mr. V. G. Pickering (Salford) considered that the limit for suspended solids (400 p.p.m) was high; at Salford 210 p.p.m. was adopted—but with considerable elasticity. He questioned the advisability of laying down a fixed standard for all trade wastes. A better plan would be to judge each waste on its merits and in conjunction with other trade wastes with which it would come in contact.

Other members discussed the danger of H_2S gas, and its production when acid and sulphur dye wastes come together in sewer systems.

In replying to the discussion, the author explained the derivation of the standards adopted by Stockport. The maximum temperature allowed (110° F.) was that permitted by the Public Health Act of 1890; the suspended solids figure of 400 p.p.m was about that of a strong sewage; the alkalinity or acidity of 2000 p.p.m. was set after tests had shown that above that amount liquors had a harmful effect on sewers.

J. K. Hoskins

SOME PROBLEMS OF TRADE WASTE DISPOSAL

By A. Sciver

Paper read at a meeting of the Institute of Sanitary Engineers, London, England, April 7, 1936. *The Surveyor,* **89,** 525–26 (April 10, 1936).

This paper deals with the influence of trade wastes upon domestic sewage and the resultant effects upon treatment processes, a problem becoming more intensive with the growing tendency to admit trade wastes to sewers rather than to provide or require separate treatment.

1. *Increase in Strength.*—Trade wastes generally increase the strength of sewage with which they are mixed. Although there is no universally accepted measure of the strength of sewage, the one most widely used is perhaps that of McGowan (Royal Commission on Sewage Disposal, 5th Report, App. 4, 1) (cf. This Journal, **8,** 339, March, 1936). Values obtained in this way from the analytical data may be classified as:

Weak sewage	Strength 60 to 90
Medium sewage	Strength 100 to 150
Strong sewage	Strength 160 to 200
Very strong sewage	Strength over 200

However, many trade effluents cannot always be classified by this procedure because they may contain only negligible amounts of materials that would react in the ammonia and oxygen consumed tests on which the McGowan formulae are based. Trade wastes although frequently not measured by the McGowan test for strength when added to sewage, often result, therefore, in mixtures much more difficult to treat.

2. *Increase in Suspended Solids.*—Suspended solids in excess of 120 to 500 p.p.m. in sewage are strongly indicative of the presence of some trade waste. High solids occasionally consist of mineral matter such as lime, chalk, china clay or silica also not registered by the tests employed by the McGowan formulae. Glue and casein wastes disrupt effective settlement. Paper and leather industries also contribute excessive suspended solids as do beet sugar factories.

3. *Change in Reaction.*—Acid or alkaline wastes that result in pH values outside the range of pH 7–8 invariably lead to trouble in biological sewage treatment processes apart from their damaging effect on concrete plant structures and equipment. In such cases industries should be required to adjust the pH value of their waste to eliminate such detrimental effects.

4. *Addition of Foul Wastes.*—Foul liquids heavily charged with malodorous substances and bacteria of decay such as wastes from tanneries, casein, glue, size and yeast manufacture increase the septic nature of the sewage at the treatment works. They can be improved by chlorination at their sources.

5. *Addition of Wastes Containing Bacterial Inhibitors.*—Phenols, tar acids, photographic wastes containing bromides and hospital wastes containing disinfectants cause trouble by inhibiting the growth of oxidizing bacteria in the purification process. Although there is no real cure for this effect, equalization of flow of such wastes to the sewer will, through bacterial acclimatisation, permit surprisingly large quantities of such materials to be handled through the treatment works without harm.

Treatment by Coagulants

Chemical precipitation is frequently helpful in reducing the load imposed on mechanical and biological treatment processes by industrial wastes. Most of the substances used, such as alumina-ferric, copperas, ferrous or ferric sulphate produce hydroxides which is settling, will include a larger proportion of the grosser solids in suspension and much of the finer colloidal matter. Lime is frequently required to adjust the pH for effective hydroxide production.

Alumina-ferric and lime are in most general use, the effective dose of each being seldom less than 30 to 50 p.p.m. Curiously enough, these materials do not increase appreciably the bulk of sludge because the mixture of sludge and coagulant tends to shrink to a volume much less than the sums of their respective volumes.

Although iron salts are used, preferably to form the ferric hydroxide, one objection is the subsequent formation of iron sulphide which, being black, causes serious discoloration. It may also later decompose and produce the odorous sulphretted hydrogen. Ferric chloride is widely used in America because it requires no aeration for the production of ferric hydroxide. However, it is hard to handle in the solid condition and the aqueous solution is corrosive and requires special containers. Iron scrap and tin cans dissolved in acid or chlorinated ferrous sulphate solution have been employed but such materials are, in England, generally more costly than the commercial chemicals such as alumina-ferric.

J. K. Hoskins

RESULTS OBTAINED FROM SEWAGE FILTERS OF DIFFERENT MEDIA

By J. Slater

Paper presented at meeting of the North-Western Branch, Institute of Sewage Purification, Manchester, England, March 6, 1936, and abstracted, with discussion, in *The Surveyor*, **89**, 444, 457 (March 20, 1936).

Of the four rectangular percolating filters of the Chorley Sewage Treatment Works, one is filled with clinker media, one with coke, one with broken sandstone and one with clinker in one-half and broken sandstone in the other half. In all cases the grading of the different materials was the same—2½ in., retained on 1¼ in. gauge—and with the exception of the first 9 in., this size was used throughout the filters which have an average depth of 6 ft. 3 in. None of the material was washed.

The filters have now been operating for nine years and for the past six years hourly samples have been taken on one day in each week of the effluents from each filter. Accordingly these results, which are presented herewith for each of the first three filters above mentioned, afford excellent comparative data produced from filters composed of different media and working side by side under identical conditions and dealing with the same tank effluent at equal rates.

The small coke continued to wash out for about 12 months and grit from the sandstone filters is still washing out after 9 years' use, emphasizing the necessity of special care in washing media and filling filter beds.

The tabulated results show that the coke filter produces the best settled effluent, the broken sandstone the worst effluent but still maintains a very good nitrate figure. Frequent microscopic examinations of the media indicate that a greater number and large variety of protozoa are present in the coke and clinker filters than in the sandstone filter.

Discussion.—In opening the discussion, Captain W. E. Speight (Bolton) commented on various types of filter media and expressed the conviction that coke was definitely the best of all materials available for the purpose, and when considered on a cubic yard basis, the cost was not excessive. Moreover, coke probably had some little understood, further beneficial action on the effluent comparable to that of charcoal and other forms of carbon when used for filtration purposes for absorbing odors.

Mr. H. Taylor (Stalyhridge and Dunkingfield) confirmed the superiority of coke over stone as a filter medium. He noted also the good drying quality of humus sludge from his filters, four of stone and one of coke. He was considering the advisability of constructing proposed new filters with lower layers of stone and upper layers of coke and expected to experiment with this combination.

Mr. W. Scott (Bury) suggested that the increased oxygen-absorbed figure of the sandstone filter was due to the presence of ferrous iron in the sandstone and that the iron oxides in the sandstone accelerated nitrification.

Mr. J. Sheard (Failsworth) stated that at his works coke filters had been in use since 1903 and had not deteriorated at all in that time. He believed coke to be by far the best medium because of its porous nature.

Mr. A. R. Ward (Stockport) inquired regarding the use of activated carbon as an aid in sewage purification by filtration where carbon losses would be reduced to a minimum. He also called attention to the danger of placing too much reliance on an average of the yearly average figures in the accompanying table in which, if the 1929 results were disregarded, the average of the remaining five years would give entirely different results.

YEARLY AVERAGE ANALYSES, FILTER INFLUENT AND EFFLUENTS

Results in Parts Per Million

Year	Average Rate per Cu. Yd. of Filter, Gals.	Oxygen Absorbed in 4 Hrs.				Solids in Suspension			Nitrate in Terms of N		
		Tank Effluent	Filter Effluent after 1 Hour Settlement			Coke	Clinker	Sandstone	Coke	Clinker	Sandstone
			Coke	Clinker	Sandstone						
1929	86	52.1	8.1	9.9	12.6	91	111	130	24.6	27.8	25.9
1930	107	47.2	8.5	9.3	11.0	80	67	93	20.8	23.5	23.8
1931	97	46.7	7.9	9.2	10.7	63	60	87	21.5	26.3	25.3
1932	92	50.3	8.7	10.2	12.0	72	60	92	22.1	28.1	25.5
1933	100	45.0	8.2	9.9	11.6	68	69	83	18.0	26.0	22.0
1934	80	58.0	9.9	11.9	13.5	97	89	79	22.0	30.0	26.0
Avg. for 6 6 yrs.	94	49.9	8.5	10.1	11.9	78	76	94	21.5	27.0	24.7
Average percentage purification effected on tank effluent			83.0	79.7	76.2						

Mr. T. Barlow (Denton) observed that the author's figures agreed quite well with those in the Report of the Royal Commission dealing with filter media. He also stressed the necessity for thoroughly cleaning media before placing them in the filters.

J. K. HOSKINS

THE DETERMINATION OF VOLUME AND WEIGHT OF WATER AND SEWAGE DISPERSOIDS

BY PROF. DR. MARTIN STRELL

Gesundh.-Ing., **58**, 533 and 750 (1935)

The water content of sludge depends on the type and degree of digestion. Fresh settled sludge usually contains 97.5 per cent moisture, sludge further concentrated by settling, 95 per cent, digested sludge, less than 90 per cent and air dried digested sludge, 55 per cent. If 3 to 9 c.c. of sludge are obtained from one liter of sewage after settling in an Imhoff cone and 0.1 to 1.0 c.c. are obtained from the effluent of a settling tank, the removal of settlable solids is 95 to 99 per cent. The water content of a flocculant, filamentous sludge, settling in a cone, is about 95 to 97.5 per cent. A more densely settled sludge may contain about 90 per cent and a centrifuged sludge, an average of 65 per cent water.

With 97.5 per cent moisture, one gram (dry basis) would have a volume of 40 c.c. With 90 per cent moisture one gram would have a volume of 10 c.c. and with 65 per cent moisture, 5 c.c.

Two examples will serve to show the calculations for determining the volume and weight of settlable solids:

One liter of freshly clarified sewage was settled in a graduated separatory funnel and the volume of settled sludge measured after two hours. The sludge was drawn into a 10 c.c. centrifuge tube, graduated in 0.1 c.c. The tube was filled to the 10 c.c. mark and after centrifuging for five minutes, the volume of sludge was observed. The supernatant liquor was poured off and the sludge removed to a weighed crucible, dried at 100–105° C. for three hours and weighed. The weight of sludge represented the dry settlable solids in one liter of sewage.

In one case, 1 c.c. of flocculent sludge had a volume of

0.3 c.c after 1 minute centrifuging
0.2 c.c. after 3 minutes centrifuging
0.2 c.c. after 5 minutes centrifuging

The dry weight of this sludge (1 c.c. flocculant sludge or 0.2 c.c. of dense sludge) was 46.7 mg. Therefore, the moisture content of the flocculant sludge was 95.3 per cent and of the centrifuged sludge, 76.6 per cent.

In another case, 1.2 c.c. of flocculant sludge from one liter of sewage had a volume of

0.4 c.c. after 1 minute centrifuging
0.25 cc. after 3 minutes centrifuging
0.25 c.c. after 5 minutes centrifuging

Since the dry weight of this sludge was 50.7 mg., the moisture content of the settled sludge was 95.8 per cent and of the centrifuged sludge, 79.7 per cent. These values agree with those obtained by analysis.

Discussion.—Dr. W. Merkel said that density of the dry solids is assumed to be 1 in this calculation. However, the density of dry solids is commonly 1.3 to 1.6 and with high sand content may be as much as 1.75. Digested sludge is about 10–15 per cent heavier than fresh solids. With a moisture content of 65 per cent, 2.86 grams of sludge would contain 1 gram of dry solids and 1.86 grams of water. If an average density of 1.4 is assumed, then 1 gram of dry solids would have a volume of 0.71 c.c. and 2.86 grams of wet sludge would have a volume of 1.86 + 0.71, or 2.57 c.c., a difference of 11 per cent. In the first case, mentionel by Dr. Strell, 1 c.c. of settled sludge or 0.2 c.c. of centrifuged sludge contained 46.7 mg. of dry solids. In 100 cubic millimeters of centrifuged sludge there are 23.35 mg. or 16.7 cubic millimeters of dry solids. The moisture content is 83.3 per cent by volume or 78.0 per cent by weight. With the settled sludge the moisture content is 96.7 per cent by volume or 95.4 per cent by weight. Dr. Merkel recommended that all moisture content values be determined by direct evaporation.

In answer to Dr. Merkel, Dr. Strell said that he believed the specific gravity of the dry solids could be disregarded on thin sludges but that it should be taken into consideration on heavy or digested sludges. The rapid method of determining moisture content is satisfactory for ordinary plant control work.

G. P. Edwards

THE INFLUENCE OF TEMPERATURE ON BIOLOGICAL SEWAGE TREATMENT

By Dr. K. Viehl

Gesundh.-Ing., **58**, 555 (1935)

According to van't Hoff's law, the velocity of a reaction increases two to three times with a temperature rise of 10° C. Although, theoretically, this law holds true, not only for purely chemical but also for biochemical reactions, ordinarily it is valid only for simple biochemical processes and within small temperature changes. At 0° C. such reactions usually proceed very slowly but with increasing temperature the velocity at first increases more rapidly than is consistent with van't Hoff's law. At some temperature above 0° C. this law begins to hold. The optimum temperature is, in most cases, about 30° C. and with further increase in temperature the velocity decreases, first slowly, then more rapidly, until it reaches zero At this stage the temperature is so high that the organisms are killed. The anaerobic decomposition of organic matter is affected by the temperature in a similar manner, except that there are two regions of great activity, one about 30° C. and the second about 55° C. (thermophilic digestion).

If the temperature affected aerobic decomposition in the same way, biological plants could be loaded twice as heavily in summer as in winter. Data from a number of activated sludge plants indicate that there is little difference between summer and winter efficiency.

In the laboratory, settled sewage was treated in a small scale activated sludge plant with a 7.5-hour detention period. The oxidation of inorganic nitrogen, between 2° C. and 25° C., proceeded approximately according to van't Hoff's law. The optimum temperature for nitrate formation was 26° C. and for nitrite formation, 35° C. Above 45° C. no nitrification occurred. The temperature also affected the clarity of the effluent with an optimum point at 29° C. The effect of temperature on aerobic decomposition of the organic matter was relatively small. Aerobic decomposition at temperatures corresponding to those for thermophilic sludge digestion was not successful, although this may be possible with certain industrial wastes which are discharged hot, such as those from yeast factories and distilleries. At low temperatures purification was poor but if this low temperature is maintained the efficiency improves. For example, at 1.5° C. the average B.O.D. reduction during the first week was 50 per cent, during the second 72 per cent, the fifth 81 per cent and the eleventh 88 per cent. Most of the excess sludge accumulated at moderate tmpratures. At 45° C. no excess sludge was formed and at 55° C. even that added was destroyed. The total number of microorganisms was greatest at 8° C. and the greatest variety was found at 26° C. to 29° C. The bacteria which decompose organic matter adjust themselves to a wide temperature range. The decomposition of phenol increased with increasing temperature, reaching a maximum at about 37° C.

Observations made on three activated sludge plants and one trickling filter plant over a period of one year indicated that the efficiency of compressed air activated sludge plants and trickling filters, which treat domestic sewage, is not affected by seasonal temperature changes. It is possible that the efficiency of activated sludge plants aerated exclusively by paddle wheels would be lower in winter, as the sewage is cooled much more rapidly by mechanical aeration than by diffused air. Obviously, seasonal temperatures have a great effect on fish ponds and broad irrigation.

Seasonal temperature changes affect the purification in rivers more than in biological treatment plants. Comparable values at different temperatures, obtained from a river investigation of several years' duration, are shown in the following table:

Temperature Centigrade	Oxygen Consumed	B.O.D. (5-day)	Chloride Number	Ammonia
Over 14	1.00	1.00	1.00	1.00
4–10°	1.06	1.01	1.51	3.33
0–3°	1.39	1.68	2.85	7.05

The efficiency of purification in the first two temperature ranges, which correspond to summer and winter conditions in a biological purification plant, was about the same, except for the ammonias. At 0–3° C. the difference was considerably greater.

G. P. Edwards

EFFECT OF NATURE OF FILLING MATERIAL AND DOSING CYCLE ON PURIFICATION OF CREAMERY WASTES

By Max Levine, G. H. Nelson and H. E. Goresline

Bulletin No. *124*, Iowa Engineering Experiment Station, December, 1935, 56 pp.

In continuation of previous studies of the treatment of creamery wastes, the effects of various filling materials and dosing cycles on the purification effected by, and the rate of discharge from, trickling filters were observed in the present study and likewise the influence of the rate of discharge on the composition of effluents. The waste was skim milk, applied at a 24-hour dosing rate of 550,000 gallons per acre, the waste being applied from 16 to 20 hours per day. The concentration of the waste varied from 200 to 1600 p.p.m. B.O.D.

Sectional lath and cinder filters and solid cinder, quartzite, gravel, spiral ring packing, broken tile (burned clay) and corncob filters were studied. All filters were 2 ft. square and 6 ft. deep. Sectional filters consisted of six sections, each 1 ft. high, separated vertically by 4-inch spaces. The dosing device consisted of a bell syphon discharging from a dosing tank through a collector into a tipping trough, which discharged into a perforated distributing tray placed above the top of the filter. The analytical data collected included oxygen consumed (by permanganate), organic nitrogen, ammonia, nitrate, B.O.D. and pH, on raw and treated waste.

Purifications with Various Filling Materials

The cinder filters gave a very high efficiency, ripened quickly and showed particularly good nitrification. They were operated successfully for four months, but after five months, excessive clogging made it necessary to wash them down to maintain their efficiency. The purification effected by the corncob filters was unexpectedly high, as measured by reductions in B.O.D. (91.1 per cent), organic nitrogen (84.7 per cent) and oxygen consumed (82.8 per cent), though nitrates were not produced. During the experiment the corncob filter shrank to less than 4 ft. deep, but its efficiency remained high for the first seven months of operation. During the last 6 weeks of the 9-month period of operation, a marked increase in the ammonia content of the effluent was observed, possibly indicating approaching exhaustion of the purification properties of the corncobs.

Although the 3-inch spiral ring packing showed the lowest purification efficiency, the results were remarkably good considering the large size of the material. Exceptionally satisfactory results are anticipated with smaller rings without the danger of clogging which eventually ensued in the cinder, gravel and broken tile media.

Poorer results were obtained from sectional filters than from solid filters of the same depth. This does not indicate that the better ventilation in the sectional filter was not beneficial, but it may have been due to irregularities observed in the distribution of waste in the five lower tiers owing to warping of the supports.

Effect of Dosing Cycle on Rate of Effluent Discharge

In the series in which quartzite was compared with cinders the effect of the dosing cycle was observed. In general it was found that variations in the dosing cycle from 2½ to 22 minutes produced little effect on the efficiency of the fine cinder filter, whereas with the quartzite filter the reduction decreased as the dosing cycle increased.

The organic content of the effluent, the oxygen consumed and the B.O.D. increased with the length of dosing cycle, but the ammonia and nitrate content remained relatively constant. This is considered an indirect indication that some of the wastes were short-circuited with the long cycle on quartzite.

The rate of run-off from the cinder filter was nearly constant and independent of the dosing cycle, in marked contrast to that observed in the quartzite filter, which varied widely and directly with the length of cycle. In this latter case, increasing the dosing cycle to 20 or 22 minutes resulted in a variability of 113 per cent, whereas in the cinder filter it was only 14 per cent.

RELATION OF RATE OF DISCHARGE TO COMPOSITION OF EFFLUENT

With the longer cycles on the coarse filters the rate of effluent run-off synchronized with the period of dosing. The maximum rate followed closely the discharge of a dose on to the filter, resulting in surges in the effluent containing large proportions of impurified waste. These fluctuations indicate that unless the run-off cycle is taken into account during sampling, high and low rates of purification may be obtained, depending on the stage in the cycle at which a sample is collected. To avoid this source of error, all of the effluent was collected during one or more complete cycles to obtain representative samples.

In general, it was found that for a given rate of application on coarse grained filters, short cycles (2½ to 5 minutes) produced more highly purified effluents, and also more constant run-off and more uniform quality of effluent. The more uniform the rate of run-off, the more nearly was the maximum efficiency of the filter approached for the load received.

CONCLUSIONS

Cinders were found to be very efficient as a filter medium for treating creamery wastes, but were observed to clog after about five months of operation.

Although the results obtained from the 3-inch spiral packing were not as good as with the other materials they were unexpectedly efficient, indicating that smaller-sized ceramic material would be particularly satisfactory.

Corncobs were quite effective in removing organic-nitrogen and oxygen-consuming constituents, but there was no evidence of nitrification and the life of the filter was limited by disintegration of the cobs.

With small-sized filling materials, the dosing cycle did not influence the purification efficiency materially. With coarse-grained materials, the short dosing cycle gave better effluents than the longer cycles (10 minutes or longer).

(The report is illustrated and contains a full tabulation of the results.)

H. W. STREETER

NORTH TORONTO SEWAGE TREATMENT WORKS

BY GEORGE PHELPS

Engineer of Sewers, Department of Works, Toronto, Ont.
Canadian Engineer, 69 (Oct. 15, 1935)

The activated Sludge plant at North Toronto has a capacity of 7½ imp. gals. daily. Twice the D.W.F. is treated through the full process and all storm flows are settled. The plant includes:

Bar Grates mechanically raked.

Grit Chambers with proportional weirs. Grit is washed.

Preliminary Sedimentation Tanks for two hour detention. Removal mechanism is Dorr equipment which is controlled automatically by telechron devices.

Aeration Tanks for six hour detention with 6 pound air applied through two rows of aeration plates.

Final Settling Tanks for 5 hour settling and with mid-tank launders for removal of effluent. Removal equipment is Hankin.

Sludge Digestion Tanks.

Covered Drying Beds provided with unit heaters.

Storm Water Tank which provides 5 mins. detention for max. flow. Sludge is discharged to the main works.

FRANK TOLLES

OPERATION OF YORK TOWNSHIP PLANT

By C. Chamberlain

Plant Sup't, York Township, Toronto, Ont.
Canadian Engineer, **69** (Oct. 16, 1935)

The York Plant was built in 1925. It now serves 65,000 people with a D.W.F. of 2½ m.c.d. The solids in the sewage average 500 p.p.m.

The plant consists of 1½ inch bar grates, grit chambers, 4-hour aeration tanks, 3-hour Dorr settling tanks, sludge reaeration channel, vacuum filters (2–8 × 8½ ft. Feinc) and storm tanks (up to 90 c.f.s.).

Average daily operating data are—air used 1.5 c.f. per gal., sludge return 29 per cent, excess sludge 35,000 gals., 2 per cent solids, ferric chloride conditioner 650 lbs., filter cake 25 cu. yds., 84 per cent moisture—14-hour filter run, grit 1½ cu. yds., screenings 1½ cu. yds. Sludge from the storm water tanks is 25 per cent organic.

Frank Tolles

OPERATION OF KITCHENER SEWAGE DISPOSAL PLANTS

By Stanley Shupe, *City Engineer*

Canadian Engineer, **69** (Oct. 15, 1935)

Kitchener has two plants. The main plant includes bar grates, detritor, settling tanks, separtae sludge digestion with gas recovery and covered drying beds. The smaller plant is an activated sludge plant with bar grates, detritus tanks, "Rotary Fine Screen Aeration," reaeration, clarification and lagooning of sludge. Data for each plant follow:

	Activated Sludge	Main Plant
Built	1925	1930–31
Cost	$70,000	$326,000
Capacity	1 m.g.d.	4 m.g.d.
Present flow	0.8 m.g.d.	3.7 m.g.d.
Degree of treatment	86%	57%
B.O.D.-Reduction—5 day	92%	39%
Operating personnel	2	9
Operating Costs 1934		
Labor	$2,264.26	$11,115.62
Power	2,514.47	463.59
Mts. supplies, maint. and repairs	982.35	2,097.96
	$5,761.08	$13,677.17
Operating per m.g.	$ 19.72	$ 10.71
Capital per m.g.	15.39	17.92
Annual cost per m.g.	$ 35.17	$ 28.63
Operating Results		
Screenings per day, wet		1,475 lbs.
Screenings per day, dry		447 lbs.
Detritor solids, per day, wet		4,000 lbs.
Detritor solids, per day, dry		684 lbs.
Clarifiers, sludge per day		14,800 gals
solids		5.8%

Frank Tolles

TANNERY WASTE STUDIES

BY E.F. ELDRIDGE

Michigan Engineering Experiment Station, *Bulletin* No. 67, March, 1936, pp. 32–47

This report deals with the results of studies made on tannery waste sedimentation at two tanneries in Michigan. Although the process used in these tanneries were similar, the results show that in some respects the wastes are different. These differences alter somewhat the effective methods of removing solids from the two wastes and indicate the need of preliminary studies whenever treatment processes are under consideration.

The study made at the plant of the Mosser Leather Corporation at Holland, was concerned with the most effective and economical method of removing suspended solids from the waste, as the problem there is largely one of preventing sludge bank formation and odors from sludge decomposition. This tannery uses the vegetable tan process for manufacturing sole leather. The wastes produced result from dehairing, lining and tanning cow-hides.

The pilot plant consisted of a 900 gallon circular coagulation tank equipped with paddles, and a 1900 gallon radial-flow sedimentation tank. In the first series of tests this plant was operated for 12 days using a 2-hour settling period preceded by coagulation for 1 hour; for 4 days using a 3-hour settling and 1½-hour coagulation period; and for 3 days with 2-hours settling and no coagulation.

The results of these tests showed a wide variation in removals from day to day, owing to "bulking" of the coagulated material, which was traced to the effect of CO_2 gas generated from mixing the acid waste with spent lime. To obviate this difficulty, the concentrated wastes from the plant were segregated and treated separately by 1 hour of coagulation and 2 to 20 hours settling in a 4000 gallon tank. The limes were separated, thus reducing the amount of sludge by two-thirds, and were mixed and dried on a sand bed with the sludge from the settling tank.

From this study it was concluded that in order to remove solids from the Holland tannery waste, (1) the limes must be handled separately, (2) the concentrated wastes settled by the fill-and-draw method, and (3) settling should be preceded by at least 30 minutes of slow stirring or coagulation and settling allowed overnight. By this method 79 per cent of the dry silids contained in the wastes were removed, the sludge amounting to about 10 per cent of the total daily flow or 30 per cent of the concentrated wastes. The sludge may be dried on sand beds in the summer and ponded in winter. It cannot be dried by vacuum filtration or centrifuging.

The second study, made at the tannery of the Eagle-Ottawa Leather Company at Whitehall, was concerned with a similar problem. In this case it was found that the limes assist in the coagulation of the suspended solids and should be treated with the other wastes, and that all concentrated wastes should be treated, these wastes being mixed in a coagulation tank for 30 minutes.

H. W. STREETER

BEET SUGAR FACTORY WASTE TREATMENT—REPORT OF THE OPERATION OF THE EXPERIMENTAL PLANT AT THE MONITOR SUGAR CO., BAY CITY, 1935

BY E. F. ELDRIDGE

Michigan Engineering Experiment Station, *Bulletin* No. 67, March, 1936, pp. 5–31

The purposes of this study were: (1) to determine the removal of solids, B.O.D. and odor-producing substances from the factory waste (flume and process water) by each of the following methods: (*a*) sedimentation, (*b*) coagulation and sedimentation, and (*c*) biological filtration; (2) to determine the same for the process water alone; (3) to determine the same for mixtures of Steffens waste with factory waste or process water; (4) to determine the volume and concentration of sludge produced by the above methods of treatment; (5) to study the feasibility of drying this sludge on the vacuum filter, and (6) to attempt vacuum filtration of lime slurry.

The experimental plant consisted of flow-regulating equipment, mixing trough, lime solution tank, lime dosing mechanism, carbon dosing machine, concrete coagulation and sedimentation basin with straight-line collector for sludge removal, sludge pump, tipping box for measuring the sludge and an experimental vacuum filter. The plant was operated 24 hours daily continuously for 52 days. Its capacity was sufficient to allow treatment of 100,000 to 200,000 gallons per 24 hours, the results being comparable with those from a full-scale installation.

The results of the study, which are summarized in a series of tables giving averages obtained from the various methods of treatment, led to the following conclusions:

(1) Where separation of flume and process water is not possible, lime treatment of the combined waste will give only slightly better removals than plain sedimentation. The quantity of lime required, 5000 lbs. per million gallons, was too great to warrant its use. Plain sedimentation should be accomplished in a tank designed for continuous sludge removal, using a two-hour settling period. The studies indicate that 90 per cent of the suspended solids and 35 per cent of the 5-day B.O.D. can be removed by plain sedimentation. The volume of sludge produced will be about 1.1 per cent of the volume of waste treated. The sludge may be ponded or dried in a vacuum filter.

(2) Steffens waste has considerable coagulating power and when mixed with combined flume and process water in factory proportions gives an excellent floc and good clarification. Where necessary to discharge Steffens Waste to a stream, this waste should first be mixed with the other factory wastes, allowed to coagulate for 15 minutes and settle for 1½ hours in a tank provided for continuous sludge removal. A small amount of lime may be necessary at times to assist in clarification. A 99 per cent removal of suspended solids and 45 per cent reduction in B.O.D. is possible. The volume of sludge will be about 1.5 per cent of that of the waste and this sludge may be ponded or dried on vacuum.

(3) The plan settling of process water alone gave 48 per cent removal of suspended solids and 24 per cent reduction in 5-day B.O.D. Coagulation with lime increased reductions to 93 and 47 per cent respectively, 600 p.p.m. of CaO being added. This additional removal warrants the use of lime in process water treatment. The volume of sludge was 1.7 per cent of that of the waste and the sludge may be dried on a vacuum filter.

(4) Steffens waste coagulates process water as it does factory waste, about 4 per cent of Steffens waste being sufficient. A 97 per cent removal of suspended solids and 45 per cent reduction in B.O.D. may be expected. The quantity of the sludge was 1.7 per cent of that of the waste and the sludge may be ponded or vacuum dried.

(5) Biological filtration of the settling tank effluent was attempted, but the added reductions obtained were too low to warrant the extra expense.

(6) The necessity of removing sand from factory waste or flume water before introducing it into a coagulation basin was a major finding in connection with the design of treatment units. This indicates the need of a grit chamber and continuous removal mechanism.

(7) The studies have shown that the following methods of treatment are applicable to the various wastes or combinations:

(*a*) Plain sedimentation of flume water for 2 hours in a tank provided for continuous sludge removal.

(*b*) Coagulation of process water with lime under similar conditions as above.

(*c*) Plain sedimentation of flume and process water combined where separation is impossible.

(*d*) Coagulation of combined flume and process water with Steffens waste where no other method of disposing of Steffens waste is available.

(*e*) Coagulation of process water with Steffens waste under similar conditions.

(*f*) Vacuum filtration of sludge and lime slurry.

(*g*) Concentration of the slurry prior to filtration.

(*h*) Biological filtration of process water only in extreme cases where receiving stream is very small.

For estimating the oxygen requirement of the raw or the treated waste on a stream in the zone immediately below the point of discharge, the author considers that in the raw waste this will be made up of two components: (*a*) the immediate or 1-day B.O.D. of the waste and (*b*) the total or 20-day B.O.D. of the suspended solids. Assuming that treatment by sedimentation would remove (*b*), the oxygen requirement for the effluent would consist of the 1-day B.O.D. For illustration, he cites average results showing a reduction of 540 p.p.m. of B.O.D. by treatment and a 1-day B.O.D. of 110 p.p.m. in the effluent. Without treatment the total B.O.D. affecting the critical zone would be $540 + 110 = 650$ p.p.m. and with treatment, 110 p.p.m.

H. W. Streeter

ANNUAL REPORT FOR 1935 OF THE WATER POLLUTION COMMISSION AND DUTCH GOVERNMENT INSTITUTE FOR THE PURIFICATION OF WASTE WATERS

By H. J. N. H. Kessener

The first part of the annual report deals with the pollution of several streams and canals. The pollution is caused by a variety of wastes, garbage, refuse, trade waste and sewage. Investigations were made and advice given in connection with waste from potato starch manufactury, straw paper, dairy, laundry, tankage, slaughterhouse, textile, wool, soap, steel, fruit canneries, dehairing and chemical industry wastes, and sewage problems for a number of communities.

Of interest is the description of cooperation with the emergency works administration. Before any emergency or relief project dealing with complete or partial sewering of towns or districts can commence, they must be submitted to the Commission, which determines not only if the plans are practical and sufficient, but whether they fit into a general system necessary for the future of a district. In addition the effect of all sewerage and drainage systems upon stream pollution is determined, and it is indicated if treatment is required to abate pollution. By not granting permission to construct or build inefficient or illogical systems the waste of considerable public money could be prevented.

Plans and pictures of several new sewage treatment plants are included in the report. Of interest are the results obtained with a practically automatic surface aeration activated sludge plant, treating slaughterhouse waste. With full load on the plant and waste including all blood the average results for the effluent were:

5 day B.O.D.	17	p.p.m.
O.C. 10 min. boiling	44	p.p.m.
Ammonia-N	23.7	p.p.m.
Albuminoid-N	1.5	p.p.m.
$NO_2(N_2O_3)$	62.1	p.p.m.
$NO_3(N_2O_5)$	14.5	p.p.m.
Alkalinity to M.O. as CaO	117	p.p.m.
Turbidity	5	per cent
pH	8.2	

The average annual operation results for a number of treatment plants of different types are shown in the following table.

Analyses	Groenlo*		Winterswÿk*		Sanatorium Apeldoorn†		Sanatorium Nunspeet		Ryswyk†		Slaughterhouse Heerlen†		Slaughterhouse Zaandam†	
	Inf.	Effl.	Inf.	Effl.	Inf.	Effl.	Inf.	Effl.	Inf.	Effl.	Inf.	Effl.	Inf.	Effl.
B.O.D. (5 day) p.p.m.	284	18	224	16	238	11	540	37	385	7	771	11	1078	9
O.C. (10 min.) p.p.m.	144	37	131	35	124	21	258	40	145	27	315	28	630	50
Total N, p.p.m.	74.4	—	40.9	—	52.9	—	68.7	—	114	—	141.9	—	179.3	—
NH_3-N, p.p.m.	70.0	6.5	31.1	5.8	46.7	4.7	56.4	6.7	109.8	2.5	82.4	20.8	54.0	1.3
NO_2 as N_2O_3, p.p.m.	—	0.9	—	2.1	—	tr.	—	1.8	—	0.5	—	2.3	—	0.03
NO_3 as N_2O_5, p.p.m.	—	150.5	—	52.1	—	87.4	—	54.4	—	112.5	—	42.1	—	338.4
Alkalinity (CaO) p.p.m.	271	96	211	129	145	6	287	178	462	193	289	162	326	48
Cl, p.p.m.	175	182	333	335	69	58	69	79	224	241	583	405	1381	1751
pH	8.0	8.1	8.2	8.3	7.9	6.8	8.6	8.3	7.9	8.2	8.3	8.3	8.4	7.9
Turbidity, per cent	43	3	37	2	28	1	46	11	56	1	50	4	7.1	1

* Trickling filters.

† Brush surface aeration.

BOOK REVIEWS

American Sewerage Practice. Volume III. Disposal of Sewage. Third Edition. 1935. By Leonard Metcalf and Harrison P. Eddy. 836 p., 6 by 9, 227 illus., 156 tables. *McGraw-Hill Book Company,* New York. Price, $7.00.

The third edition of "Metcalf and Eddy" is the most comprehensive and most informative book on sewage disposal in the English language. It is comparable to the monumental German work by Brix, Imhoff and Weldert (Vol. II), but actually it appears to contain more data and more concentrated information than the German work.

The new edition has been brought up to date and includes data on design or operation of practically all American sewage treatment plants. The book is so complete that it is difficult to point out any deficiency. Possibly some condensation could be attempted, with discrimination, in chapters on contact aerators, automatic dosing apparatus, sewage irrigation and elsewhere, and on the other hand possibly separate sludge digestion could be expanded, but on the whole there seems to be excellent balance in the scope of treatment. One can hardly think of any phase of sewage treatment that has not been thoroughly discussed.

The intelligent work that has gone into this book is truly enormous, and the result is a tribute to Mr. Eddy and his loyal associates who may take just pride in this work.

No detailed review of chapters or topics is necessary, for the book has "everything." It is urgently recommended to every sanitary engineer or chemist.

F. W. M.

Handbook of Sewage Disposal. Seventh Edition, 1936. By Karl Imhoff. 195 p., 58 illus., 15 tables. *R. Oldenbourg,* Munich. Paper covered, 5.4 R.M. ($2.20).

This well known handbook, now in its seventh edition, is world-famous. The last edition has been translated into five languages. It is to be hoped that the present edition will be translated into English by Prof. Fair, who translated Dr. Imhoff's *Arithmetic of Sewage Treatment Works.*

The book is small, measuring approximately 5 by 7 inches, but a large amount of information is compressed within its 195 pages. The value of the book lies in the experience, judgment and discrimination of its author, who has tested all things and held fast that which is good.

Sewerage design is treated in the first 36 pages, followed by 15 full-page plates with curves of rainfall, capacities, cross-sections, slopes, etc.

Sewage treatment then comprises 127 pages, treatment works design problems 10 pages, and self-purification of streams, with problems, 16 pages. The index and a table of equivalents complete the 195 pages.

The new or noteworthy features are: the chapter on stream pollution, adopted largely from Streeter; the short chapter on chemical treatment; the table of cost data; and the thorough treatment of sludge digestion. Weaker sections are: the single page on chlorination; and the four pages on industrial wastes.

Americans who can read German will find this little book a delight; those who do not will have to wait for the translation.

F. W. M.

The Fundamentals and Procedures of Modern Sewage Treatment. By H. Bach. 178 p., 78 illus. *Akad. Verlagsgesellschaft,* Leipzig. 1936. Paper covered, 10.5 R.M. ($4.25).

Dr. Bach's new book is one of a series of monographs which deal with recent advances in various lines of chemistry. The work is therefore essentially a review of modern sewage treatment, but Dr. Bach also includes the historical development of the various types of sewage treatment processes.

There are fifty chapters, of which the most valuable are those on the biology of sewage, the digestion and disposal of sludge, and the physical, chemical and biological factors in sewage treatment. The theory of sewage treatment processes is discussed admirably and many scattering analyses are given for the sewages of various cities, but these tables are of little value because no data on flow per capita are given.

In general, the book suffers from lack of structure, and lack of appreciation of the engineering viewpoint. The treatment is largely qualitative and somewhat diffuse. There is little appreciation of the use and value of the B.O.D. test in sewage treatment, industrial waste evaluation, or stream pollution studies. However, this is no serious fault, as the wide scope of the book would hardly permit any elaboration of details.

Although the book is devoted almost entirely to German practice, Dr. Bach mentions and is cognizant of progress in other countries. For many years he has been the leader of German sewage chemists, and this book reflects his wide experience and mature judgment. His American colleagues ought to read this book, to become more familiar with German sewage practice (and Dr. Bach).

F. W. M.

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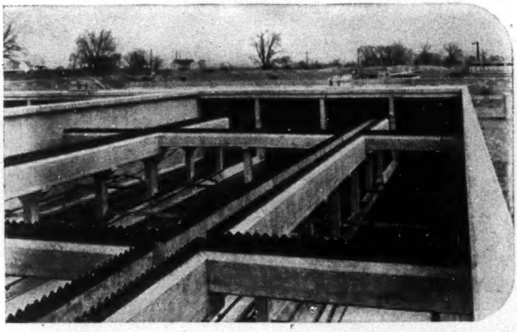

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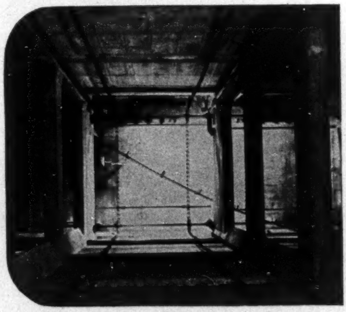

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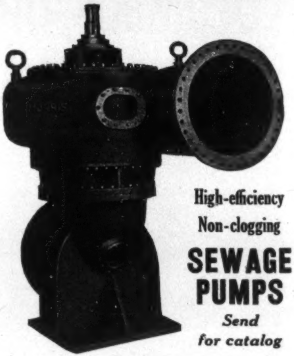

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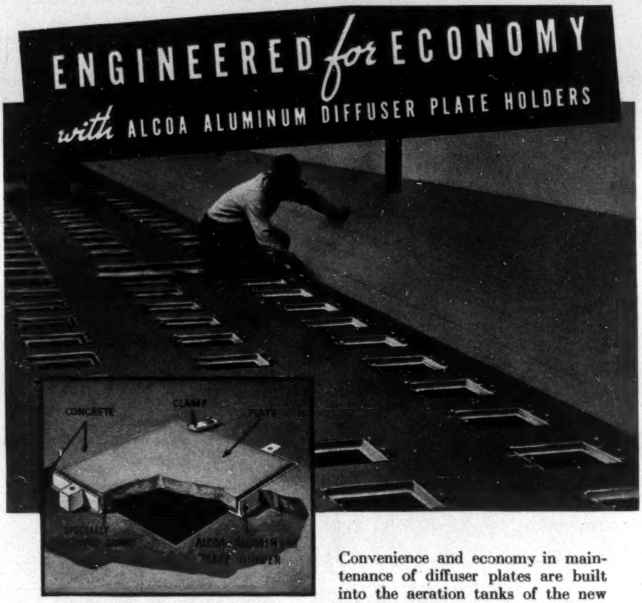

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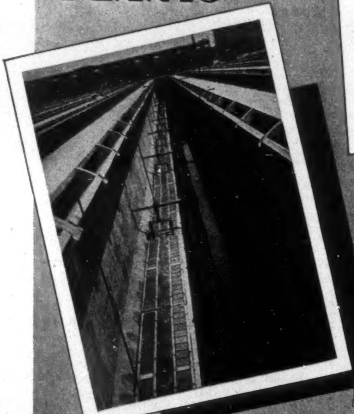

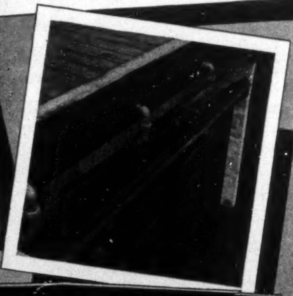

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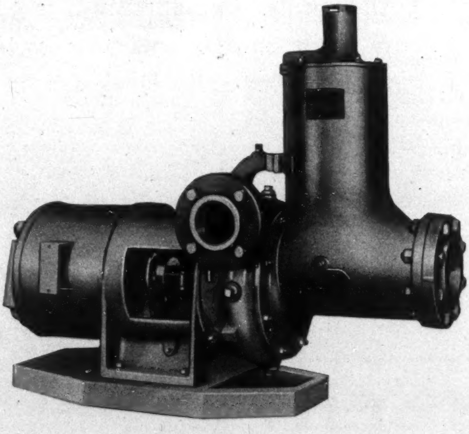

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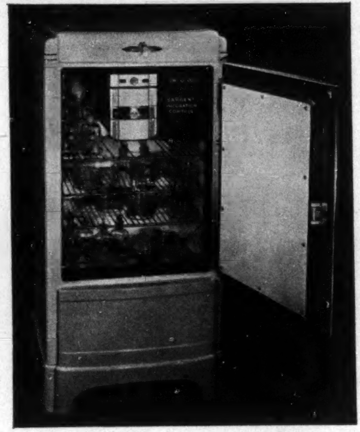

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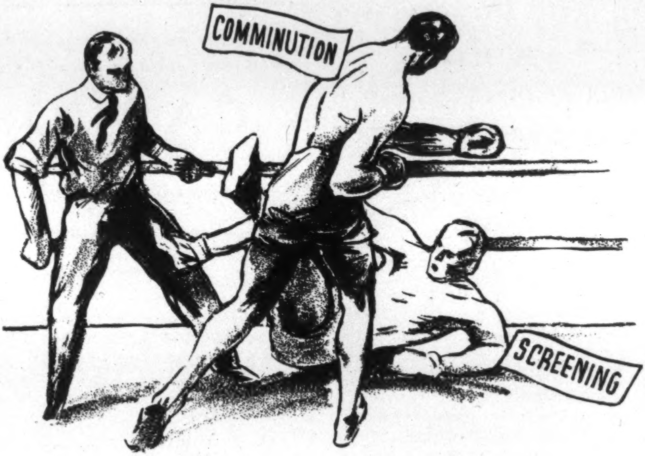

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